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ASSESSING LAND-USE IMPACTS OF THE RIO DE JANEIRO LRT AS PART OF THE PORTO MARAVILHA PROJECT.

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To my family.

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First at all, I would like to thank God because your promises never fail.

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ABSTRACT

Seen as a strategy to promote the development and spatial transformation in urban areas, sporting-related mega-events have been commonly used by cities worldwide aiming to boost the economy while promoting urban development. Often creating a new image of the city, the Large Urban Projects are highly related to spatial transformation involving changes in land use occupation and transport infrastructure.

The City of Rio de Janeiro has passed through massive changes since the implementation of the Porto Maravilha urban project aimed at redeveloping the Port region and hosting two mega-events - World Cup (2014) and the Olympic Games (2016). Among the spatial transformations in the transport system, the deployment of the Light Rail Transit (LRT) represented one more effort to enhance the city's accessibility and attract people and activities to the region. Face such context, the present study aims to analyze the land use transformations occurred since the LRT deployment, concerning population density and mixed uses, particularly in the immediate surroundings of three stations: Vila Olímpica, Santo Cristo and Harmonia. The methodology applied a time-frame approach to investigate changes in land use occupation in the period pre-and post-implementation (2010-2020).

The results have shown that although the changes revealed below the expected, the station's surroundings presented higher populational growth when compared to the performance in the overall region. The land-use changes showed more relevance to institutional, commercial and mixed uses (residential and commercial) as a result of the implementation of large sporting buildings and the conversion of traditional industrial warehouses in bad-conservation conditions. The results also revealed that although covering the local communities living in the LRT surroundings, their socio-economic characteristics do not correspond to the potential users.

This work represents a contribution to future researches to foment the current debate on the impacts on the land use system with the implementation of a transport infrastructure.

KEYWORDS: LRT; implementation; land-use changes; Rio de Janeiro; Porto Maravilha Project.

RESUMO

Vistos como uma estratégia para promover o desenvolvimento e a transformação espacial em áreas urbanas, os megaeventos esportivos têm sido comumente utilizados por cidades em todo o mundo com o objetivo de impulsionar a economia e promover o desenvolvimento urbano. Muitas vezes criando uma nova imagem da cidade, os Grandes Projetos Urbanos estão altamente relacionados à transformação espacial que envolve mudanças na ocupação do solo e na infraestrutura de transporte.

A cidade do Rio de Janeiro passou por grandes mudanças desde a implantação do projeto urbano do Porto Maravilha, voltado para a requalificação da região portuária e a realização de dois megaeventos - Copa do Mundo (2014) e Jogos Olímpicos (2016). Dentre as transformações espaciais no sistema de transporte, a implementação do Veículo de Trânsito Ligeiro (VLT) representou mais um esforço para melhorar a acessibilidade da cidade e atrair pessoas e atividades para a região. Diante desse contexto, o presente estudo tem como objetivo analisar as transformações do uso do solo ocorridas desde a implantação do VLT, no que se refere à densidade populacional e aos usos mistos, principalmente no entorno imediato de três estações: Vila Olímpica, Santo Cristo e Harmonia. A metodologia aplicou uma abordagem de temporal para investigar as mudanças na ocupação do solo no período pré- e pós-implementação (2010-2020).

Os resultados mostraram que embora as mudanças tenham se revelado abaixo do esperado, o entorno da estação apresentou maior crescimento populacional quando comparado ao desempenho da região como um todo. As mudanças no uso do solo mostraram-se mais relevantes para os usos institucionais, comerciais e mistos (residencial e comercial) em decorrência da implantação de grandes edifícios esportivos e da reconversão de galpões industriais tradicionais em mau estado de conservação. Os resultados também revelaram que, embora abrangendo as comunidades locais que vivem no entorno do VLT, suas características socioeconômicas não correspondem aos potenciais usuários.

Este trabalho representa uma contribuição para pesquisas futuras para fomentar o debate atual sobre os impactos no sistema de uso do solo com a implantação de uma infraestrutura de transporte.

PALAVRAS-CHAVE: VLT; implementação; mudanças no uso do solo; Rio de Janeiro; Projeto Porto Maravilha.

SUMMARY

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ACRONYMS

CEPACs - Certificates for Potential Additional Construction (*Certificado de Potencial Adicional de Construção)*

IBGE – Brazilian Statistic and Geography Census Institute

IPTU - *Territorial Tax on Urban Property (Imposto Predial Territorial Urbano)*

LRT – Light Rail Transit

OUCPRJ - Urban Operation for the Port Region of Rio de Janeiro *(Operação Urbana Consorciada da Região do Porto do Rio de Janeiro)*

PAC – Growing Acceleration Program (Programa de Aceleração do Crescimento)

PPP - Public-Private Partnerships

ZUM – Mixed Uses Zones

1
INTRODUCTION

Seen as a strategy to promote development and spatial transformation in urban areas, sporting-related mega-events have been commonly used by cities worldwide aiming to boost the economy, improve the competitiveness in the global tourist market, enhance transport and service infrastructures, as well as to create vibrant cultural atmosphere (Lindau, Petzhold, Tavares, & Facchini, 2016)

Large Urban Projects are characterized by three aspects, related to the a) magnitude and impact of the structures; b) spatial transformation involving changes in land use occupation; and c) the emblematic character of the projects often associated to a new image of the city.

The contemporary urban management involving to host mega sporting events - such as World Cup and Olympic Games – called by Harvey (1996) of Urban Marketing or Urban Entrepreneurship, is also characterized by the participation of the private sector to allow the economic realm so the urban transformations take place.

Recently, the City of Rio de Janeiro – one of the major Brazilian cities -, has received not one, but two of these mega events in a time-frame of two years – World Cup in 2014 and Olympic Games in 2016. These occasions have brought massive changes in the overall city, particularly in the Port region since the deployment of the Porto Maravilha urban project. The Urban Operation for the Port Region of Rio de Janeiro - OUCPRJ *(Operação Urbana Consorciada da Região do Porto do Rio de Janeiro)* – is a mega urban intervention aimed to revitalize 490-hectare area comprised by three neighborhoods Saúde, Gamboa and Santo Cristo, adjacent to the Downtown of Rio de Janeiro.

The Porto Maravilha project was aimed at revitalizing the Port region, attract urban ad economic development and attract new inhabitants improving the densities of the region. Therefore, since 2009, the city has received massive investments in accessibility and mobility, sanitary infrastructure, housing sector and leisure and cultural equipment. Among the spatial transformations in the transport system – such as the demolition of an “elevated” highway, construction of the binary, tunnels, cable car, Bus Rapid Transit – the deployment of the Light Rail Transit - LRT from now - represents one more effort

to enhancing the city's regional accessibility and connectivity with the other transport modes in the current decade. The LRT was designed to interconnect several transport modes, such as the subway, the airport, maritime and buses terminals, the BRT, and others, bringing a substantial change the in the area.

The literature recognizes a direct relationship between the availability of transportation and the development of activities in urban space. On the other hand, it is also known that the spatial distribution of activities, housing, commerce and workplaces create demand for transportation, so people can access them. Changes in accessibility in a given area have a great capacity to increase the attractiveness, and to create other impacts, such as inducing changes in land value and properties, uses, densities, etc. These impacts can be understood as results of the change in the relationship between transportation supply, land use and the human activities developed. A change in this relationship has the potential to create greater demands for transportation infrastructure, investments in urban and population growth management.

A very common reality in current context of large urban centers involves traffic and congestion concerns. Becoming one of the main urban problems and directly related to the quality of life of its citizens, congestion also influences the demand for employment, leisure and distribution of its resources. To mitigate such problems, contemporary cities have been changing their priorities from planning to road-based mobility to planning to accessibility of people and places by prioritizing transit transportation.

Public transportation with higher passenger capacities has been increasingly inserted in contemporary cities, promoting benefits such as: reduction of individual vehicles on major routes, reduction of travel time, improvement of quality and speed of public transportation services, etc.

In this way, mass transportation has as one of the alternatives to the growing demand for transportation in cities. It can be pointed out that one of the most frequent options of mass transportation implanted in contemporary urban centers is the LRT, which despite its lower passenger number capacity than the traditional subways and trains, presents greater flexibility for its routes and lower prices for implantation. However, as a transport infrastructure, the implementation of the LRT system has a direct impact in land uses and activities, especially in the immediate surroundings.

Research objective.

Accordingly, the present work aims to analyze the impacts in the land use system (density, mixed uses) occurred since the implementation of the new transit infrastructure, particularly with regard to the so called “Carioca LRT” in the City of Rio de Janeiro, Brazil.

To achieve the main objective, it is important however to understand this project as part of a mega project with a larger scale of urban intervention – and not isolated -, with the objective of revitalizing

and reordering the region (Port and city Centre) with associated projects in various sectors. The LRT project is part of and complements the urban operation Porto Maravilha, which has among its main objectives to improve mobility conditions and increase the density in the Port Region, characterized for decades for the low occupation densities due to tits industrial character.

Methodology.

Considering a time-frame approach from 2010 (before) to 2020 (after), this study is intended to analyze the impacts of the implementation of the LRT infrastructure to evaluate its impacts in the current urban context. Accordingly, the research will be focused at to analyze the impacts on the implementation of LRT in Rio de Janeiro with regard to the land use characteristics (density and diversity) particularly in the local communities in the surrounding of three specific LRT stations.

Through the delimitation of a 500-metre route-distance from each one of the three stations, we analyze the changes in land use conditions in the immediate surroundings occurred in the last decade (2010-2020) as a result of the Porto Maravilha's rehabilitation project, with attention to the deployment of the LRT network. In this way, positive and negative impacts will be studied in a comparative approach, according to the collected data in the periods before and after its implantation.

The focus of this work will be the analysis of the land use factors in the areas comprised by the influence of the LRT modal stations in pre- and post-implementation periods, but also consider - by effect of comparison - the broader region of the Porto Maravilha project. In addition to the land uses and densities, the investigation also analyze the degree of which the population living in such region match with the LRT users' profile.

Accordingly, in this work the land use and individual's data will be used in order to seek possible spatial and social consequences provoked by the implantation of the referred transport in the Port region and the surroundings of the LRT stations.

Structure.

The present study is organized as follows. In the introductory Chapter 1, we present the background, research objective, methodology and structure of the present work; Chapter 2 provides the theoretical knowledge on which this research based with respect to mega-event cities as a planning strategy to revitalization of deprived regions; Chapter 3 presents the methodology used since the definition of the study areas, the quantitative method of analysis and approach; Chapter 4 presents our case study regarding the estimated scenario before and after the LRT implementation. Chapter 5 discusses the results of the evaluation post-implementation with regard to the analyzed factors. Chapter 6 present the main conclusions and final considerations.

2

MEGA EVENTS, TRANSPORT INFRASTRUCTURES AND LAND-USE CHANGE

2.1. MEGA-EVENT CITIES

There is a clear relationship between urban planning and communication of a specific image of the city developed around the mega-events called "Olympic Urbanism" (Muñoz, 2016). Mega-events – such as Football World Cup and Olympic Games - are large cost one-time occasion that attracts a large number of visitors due its worldwide media reach and produce in the host cities great impacts on the built environment and the local population (Müller, 2015a).

Over the course of 20th century mega-event has been commonly used as a strategy to promote development and spatial transformation in urban areas (Muñoz, 2016), allowing the host city to boost the economy, improve the competitiveness in the global tourist market, improve transport and service infrastructures, create vibrant cultural atmosphere and establish a network of high-grade facilities (Lindau, Petzhold, Tavares, & Facchini, 2016).

Increasingly after the Second World War, the discussion of sporting-events has changed from around architectural styles of enclosed spaces to becoming part of the process of expanding the urban territory and promoting transformation of existing built urban environments (Müller, 2015a; Muñoz, 2016). Due to the repetition over time, mega-events have assumed a global importance attracting a huge interest of people and investments.

Through the implementation of large urban projects, mega-sporting events correspond to an alternative to stimulate new ways of occupying deprived urban areas, promote spatial transformations and – when carefully implemented - promoting social, economics, politics and environmental benefits (Zenato & Silva, 2017).

2.1.1. MEGA-EVENT AS A PLANNING STRATEGY

In the ongoing context, many cities worldwide have taken the entrepreneurial approach to urban spatial management to boost their economy and become competitive in the global market (Harvey, 1989, apud. Sanchez & Broudehoux, 2013; Muñoz, 2016).

The urban entrepreneurship - also known as City Marketing – is based on the collaboration of public management/administration with external (private) agents which became very commonly used since the globalization process (Harvey, 1996). According to Harvey, such an approach sees the city as a "product", within the neoliberal logic of reconfiguring the city through the “privatization and commodification” of urban spaces and the implementation of market-oriented policies (Sánchez & Broudehoux, 2013). The notorious “public-private partnerships” (PPP) are one of the most known strategic tools for contemporary urban management.

Aligned in this perspective, mega-events are seen by some as an urban development strategy, not only to boost the promotion of places (by enhancing media visibility) but also an opportunity for economic regeneration (Sánchez & Broudehoux, 2013). By prioritizing the local agenda and attracting investments, the one-time occasion has a great potential to improve the place’s economy and promote regeneration of urban areas or deprived part of the city.

It is recognized that mega-events create unique and exceptional conditions characterized by the facilitate the implementation of large-scale urban projects involving large investments and spatial transformations. Supported by what some call the ``Olympic State of Emergency (Sánchez & Broudehoux, 2013), the suspension of regular laws is one of the characteristics in the planning process of cities that host mega sporting events. In order to be able to host mega-events, the city has to adapt its dynamics and infrastructure to respond to the event demand, which is often enabled by opening exceptions in municipal, regional and even national laws. Thus, acting as a strategic tool to bypass the political processes, the implementation of mega urban projects is, in almost all cases, based on the "exceptionalism" or through special legislation that temporarily suspends the regular laws (Lindau et al., 2016; Muller, 2015b).

The exceptionalism allows new forms of governance and attraction of investments - through public-private partnerships - this tool ends up reducing the power of the local government in the decision-making and management of such mega-projects. With the limited decision-making power of local governments (Muller, 2015b), the concern is that big decisions are often made by those who are in charge of implementing the projects – large building companies and construction enterprises – aimed to maximize the profit. Thus, although fostering a range of urban transformations – infrastructure;

mobility; sport and cultural equipment -, such punctual and speculative urban projects in public-private collaboration often set aside more urgent local concerns (Harvey, 1996)

Although the recognition of the mega-events' legacy in inducing urban development, negative impacts on cities and regions occur in almost all cases which Muller (2015b) prefers to call as a "Syndrome of Mega-event" (Muller, 2015b, p.7). After running the mega-events, there is a range of symptoms left in urban dynamics. Overbudget cost, oversized infrastructure and social polarization from the [promised] positive urban development, among others, are some examples of negative-impact symptoms induced by the implementation of large urban projects based on the mega-sporting event.

Firstly, the overbudget cost is related to the bidding (tendering) process, since involving several companies that compete for the right of implementation of the large urban project the initial cost is often minimized. However, with a long implementation period (sometimes takes over than 10 years) and a fixed deadline, much can go different from the initial plan resulting in most of the cases in overbudget cost.

Secondly, infrastructure designed to respond to the mega-event which is non-divisible (i.e., the competitions happen from day one "at full force"). Also, the event attracts a high number of people (national and international visitors) which does not correspond to the real demand in the normal scenario. Thus, after running such events, it is not rare to find mega infrastructures and large buildings unused due to the lack of demand and high cost to operate/maintaining.

Third, the polarization, gentrification and social exclusion caused by the improvements to the event, which often turn their backs on the needs of the local population. Large urban projects guided by mega events promise positive results economically, based on the large investments made, but usually end up highlighting the existing social inequalities (Muller, 2015b; Zenato & Silva, 2017).

Thus, it can be said that the emphasis on tourism, the production and consumption of shows, the promotion of ephemeral events are immediate palliatives but in general they are highly speculative. Sanchez & Broudehoux (2013) reinforce such argument discussing how this type of planning model (sporting event-based) fosters "*an exclusive vision of urban regeneration that can open the way for the state-assisted privatization and commodification of the urban realm, thus serving the needs of capital while exacerbating socio-spatial segregation, inequality, and social conflicts*".

As a result of the execution of large urban projects to hosting such mega-events leads to the valorization of the image of the city, which turns degrading scenarios into postcards (Zenato & Silva, 2017). Especially in the case of the so-called developing countries, the image is sold to the world while turning their backs to the peripheral areas not covered by such projects. Directly affected by the territorial

changes (new infrastructure and land use occupation) from the implementation of large urban projects, vulnerable populations living in such regions end up to be socio and spatially excluded.

One of the biggest debates around mega-events is due to the redirection of the strategic planning of the city due to the occasion, in the way that instead of promoting urban development, the urban development becomes an instrument of the mega-event (Müller, 2015a). In his work, Muller cites Rio de Janeiro as an extreme example where the government makes from the mega-event priorities a driver to development and progress to the city. In fact, in a period of 10 years, Rio hosted 3 major international events - Pan American Games (2007), the Football World Cup (2014), and the Olympic Games (2016) – which has led to a decade of infrastructure transformations aimed purely at serving sports dynamics.

2.2. MEGA-EVENTS AND SPATIAL TRANSFORMATION

According to Muller (2015a), four dimensions define a mega-event: high visitor or tourist attractiveness, wide media reach, increased cost and significant urban transformations. In fact, such a fourth dimension is seen as fundamental so the event is considered as a mega-event. In the author's words, *"an event that does not intervene to a significant degree in its host city, region or even country would thus not qualify as a mega-event"* (Muller, 2015a, p. 634)

Among the analyzed studies on large urban projects related to mega-events, two main focuses are commonly found related to the urban structure's changes: improved transport infrastructure and land use occupation transformations.

2.2.1. TRANSPORT-BASED INFRASTRUCTURE

One of the main characteristics related to mega-events is the great spatial transformation that the host city goes through years before the realization – or the "urban legacy". Due to its large size and mediated reach, the occasion of a mega-event assumes an emblematic character attracting a large number of people and requiring extensive investments in terms of transport infrastructure.

Improving the access between people and places dispersed in the urban territory is one of the most important investments and an essential input mega-events' transformations. Since the events often occur in a specific area(s) of the city, the need to connecting places of interest, such as historic center, main centralities[1], airport and bus terminals, stadiums, staff allocations and tourist settlements are some of the main concerns in the realization of mega-events.

In line with broader recent concerns about promoting sustainable mobility in urban areas, cities that host mega-events have turned their focus on transporting systems by a multimodal approach, that is,

[1] Centrality refers to the concentration of services, jobs, entertainment and other activities that a transport station or a multi-modal center can attract to (Ewing, Pendall and Chen, 2002).

combining different transport networks: boat, rail, buses, and non-motorized modes (cycling and walking).

Serving passengers with lower implementation cost has been the primary aim of the new rail projects (Cevero, Journal Report: Light Rail Transit and Urban Development, 1984) commonly known as Light Rail Transit (LRT). Since the last several decades, the LRT has become a very popular mass transport mode potential to promote urban development and revitalizing central city areas.

As a heavy rail transport, the LRT comprises a fixed guideway corridor between stations, and thus has a direct impact in the immediate surroundings. Especially in the vicinity of the LRT stations, its implementation affects land use occupation, promotes regeneration of deprived areas, influences urban growth and increased property values (Cevero, Journal Report: Light Rail Transit and Urban Development, 1984). Some of such impacts will be better discussed in the next subsection.

Other relevant aspects on the implementation of LRT stations relate: regional and transit accessibility, and connectivity.

The concept of accessibility became widely known since Hansen's definition as “the potential of people to interact” (Hansen, 1959). Studies define regional accessibility as the relationship between an individual site´s location to the city’s historic Centre (Kuzmyak & Pratt, 2003; Edwin, 2005). Enhancing the regional accessibility by combining all different transport modes composed by the transport system is one of the planning strategies to improve the potential of mobility in cities.

The deployment of LRT, and the localization of stations contribute to the improvement of transit accessibility. This factor refers to the quality of the transit, when it is serving a specific location, as well as the facilities for accessing the different modes possibilities. Cervero, et al. (2004) relates the combination of increasing residential/commercial density and the improvement of walkability around stations offer conditions to transit ridership, varying the level of transit commute mode split from 20% to 27%. Cervero found that when the residents are living near transit stations, they are more likely to commute by transit.

Bailey (2007) found that the residents living in the surrounding areas of public transport stations have fewer daily vehicle travel, reducing the car dependency, and decreasing the rate of households with two cars. These results are directly affected by the offering of high quality of public transit service and the accessibility among stations, residences, services and jobs.

Badoe and Miller (2000) indicate in their study that transit service can facilitate land use development patterns, but this is just one of many factors. If an area is ready for development, the deployment of LRT and the stations can provide an additional reinforcement for higher density development.

Since to travel by transit people need to walk from or to the transit stations, most of the research focused on transit accessibility also relates walking and cycling trips. This is another factor linked to pedestrian-friendly environment, such non-motorized transportations are directly affected by the conditions of sidewalks, the paths and connectivity, pedestrian support and facilities, the improvement to the walking and cycling conditions is going to allow the increasing of non-motorized travels, and it increases the transit travel and reduce automobile travels (VTPI, 2005).

Cervero and Radisch (1995), found that the residents living in pedestrian-friendly communities use to walk or bike 49% of work travels and 15% of their non-work travels, if compared with automobile-oriented community – which in turn use to walk or ride bikes 18% of work travels and 11% of their non-work travels. In the same understanding Handy and Mokhtarian (2005), found that residents tend to walk more and further when living in more walkable communities, that are more conducive to foot travel, and a portion of this resident substitutes for driving.

Finally, improving the connectivity between different modes of transport/infrastructure promotes more options for alternative modes and a well-designed public transportation system. Some indexes were found in the literature to evaluate connectivity (Handy, Paterson and Butler, 2004; Dill, 2005) which measure the level of connectivity combining all modes: non-motorized modes (pedestrian, cyclists), private cars and public transportation.

According to Bento, et al (2007), the residents can reduce automobile travel, when living in a non-dispersed area and covered by a multi-modal surrounding. Considering the deployment of the LRT in the area, and according to the authors, the resident can have an environment that improves multi-modal trips, with the possibility to complete parts of the work trips with different means of transport, railway, cycling, walking or in other alternative ways.

2.2.2. Land Use Changes Induced by Transport Improvements

The majority of the early works about the deployment of LRT in the cities are focused in two different approaches: the viability of the system concerning the offering of a mix of activities near the stations, and the influences of the travel choices within a certain radius of distance from the stations. However, this paper has chosen a different approach about this subject, to study the impacts of deployment of LRT in the urban fabric, regarding some criteria that allow an analysis of the changes around LRT line after its deployment.

To analyze the transformations in the urban fabric by a transport system, it is necessary first to realize that land use and transportation are directly linked in a cause-and-effect relationship, the decisions taken to implement transport impact the urban environment. The understanding of transportations systems and land use planning decisions are in part contradictory and complement each other. For this study is used

as criterion for analyses of the LRT system, the observance of the changes of the indexes of land use factors since the deployment of this specific transport modal.

Different land use factors are used to study the impacts of a transport system in a specific area. In this investigation, the chosen factors are: i) population density and ii) diversity of uses.

2.2.2.1. Population Density

The density is appointed in the literature as the quantity of people or the number of jobs that can be counted in a determined area (Campoli & MacLean, 2002). It is important to recognize that the density can be measured according to different scales, from global levels to specified micro zones.

Studies have shown that density is an important factor to the functioning of the transport system in cities. Polycentric urban environments are very favorable to the deployment of public transport infrastructure because the existing people and activities create a fair demand to its economic profit. On the other hand, when a new transport infrastructure take place in a low-density location, it is likely that the new infrastructure attracts new residents to live and work in this area, and thus increase density.

A study developed by Kuzmyak & Pratt (2003) describe the relationship between land use density and travel behavior. Due to its relation to people's travel choices derived by the presence of transport supply, population density can be used to measure the impact of the deployment of a new transit infrastructure in a given area.

According to the literature, when a specific area presents increasing in population density, the number of potential destinations tends to increase too (VTPI, 2005). There is a strong relationship between the increasing of the amount population in a specific area to the number of travel options available, as a consequence of the economy of scale, that provides facilities and public services accessibility.

The increasing of the density in an area also affects the choices of the modes, and has the potential to make the use of automobiles less attractive (Faucett & Research, 1999). A denser environment might increase congestion and parking demand as a result of increased automobile users. Also, the increase of density tends to decrease the travel speed and trip distances (Levinson & Kumar, 1997).

Ewing (2005) and Kockelman (1995) had an interesting conclusion with their studies, that the impact of the density on travel choices is stronger when associated with other land use factors, such as: regional accessibility, land use mix and walkability.

2.2.2.2. Land use mix

This factor refers to the existence of different types of land use in the region, the usual land uses are residential, commercial, institutional, recreational areas, etc. This mix can vary according to scale and

category, from a small area to a neighborhood or city, as well as the variation of a specific characteristic of residential occupation to a mix of housing types and prices. Such possibility to create such mixing in the cities, is linked to the features of the New Urbanism (VTPI, 2005).

The insertion of the LRT in the urban fabric is usually designed for mixed-use centers, offering accessibility and connectivity to a large number of users. According to (Modarres, 1993; Kuzmyak and Pratt, 2003), the improvement of mixed use of land can reduce travel distances, and residents and employees in these areas tend to choose public and alternative modes of transportation.

The concept of Job/Housing Balance, according to Weitz (2003) and Kuzmyak & Pratt (2003), refers to the proportion of use residential to the offering of jobs in an area. There is an evidence that larger number of job types offered in an area can affect the commute distance. Crane and Chatman (2003) indicate that when we have more concentration of residents and local workers consequently, we have increased short-commute distances.

3
METHODOLOGY

This study aims to investigate the changes in land use characteristics in the immediate surroundings of the LRT stations – Santo Cristo, Vila Olímpica and Harmonia – that occurred during the last decade as a result of the implementation of the Porto Maravilha regeneration project aimed to host the two mega events in Rio de Janeiro.

This chapter begins by presenting the general context of the Porto Maravilha Urban Regeneration project to understand the transformations that occurred in the entire area of the urban intervention. The following section (3.2) explains the method of analysis, its scope, time frame and study areas' definition which will be analyzed comparatively to the "global reference" presented by the first section (3.1). The section 3.3 presents the indicators considered in this study – population density and mixed uses - and, finally the section 3.4 presents the data source used in the study.

3.1. PORTO MARAVILHA URBAN OPERATION

The Urban Operation for the Port Region of Rio de Janeiro - OUCPRJ *(Operação Urbana Consorciada da Região do Porto do Rio de Janeiro)* – is a mega urban intervention aimed to revitalize 490-hectare area comprised by three neighborhoods Saúde, Gamboa and Santo Cristo, adjacent to the Downtown of Rio de Janeiro. Seen as a great potential for enhanced residential, commercial, entertainment and cultural uses due to its close proximity to the city's center and to Rio's waterfront, this area also has very good transportation access and regional accessibility due to its spatial location.

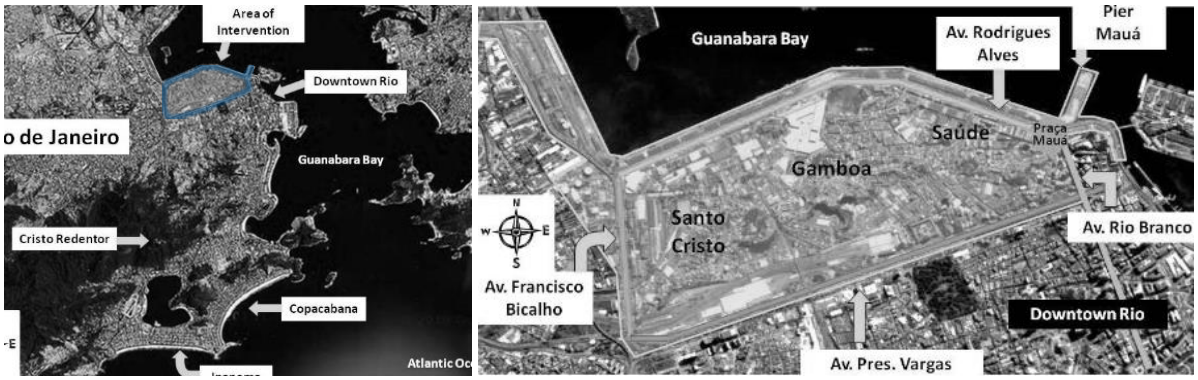


Figure 1 - Location of the Port Region in Rio de Janeiro.

Aiming to revitalize the [at time] underutilized and run-down Port district, to attract economic development, and to increase the population density in the region were the main objectives of the Porto Maravilha project. The mechanism to attract urban redevelopment to the entire region was possible through the creation of CEPAC's (*Certificado de Potencial Adicional de Construção)*. Through the sale of Certificates for Potential Additional Construction, a singular instrument for obtaining private sector financing for urban interventions, development "air rights" in areas that will benefit from large scale infrastructure improvements (Amsler, 2011) extending the building potential becoming attractive to more people living and working in the region.

The following figure explains the CEPACs as an urbanistic instrument for financing urban interventions by the private sector. To stimulate new inhabitants, the potential of construction defined by the law will be free of fees (IPTU) in a time frame of 30 years. The Potential Additional Construction increases the build-right for those who are interested to build beyond this limit, giving the financial support integrally which is used to improve the region as a whole.

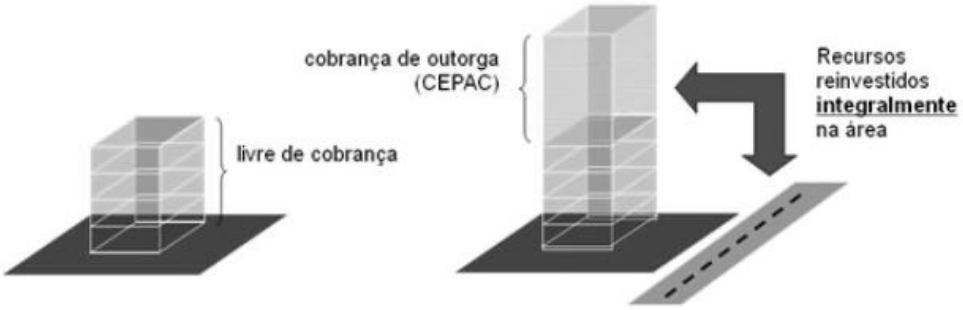


Figure 2 - Explaining the Potential Additional Construction. Source: CDURP.

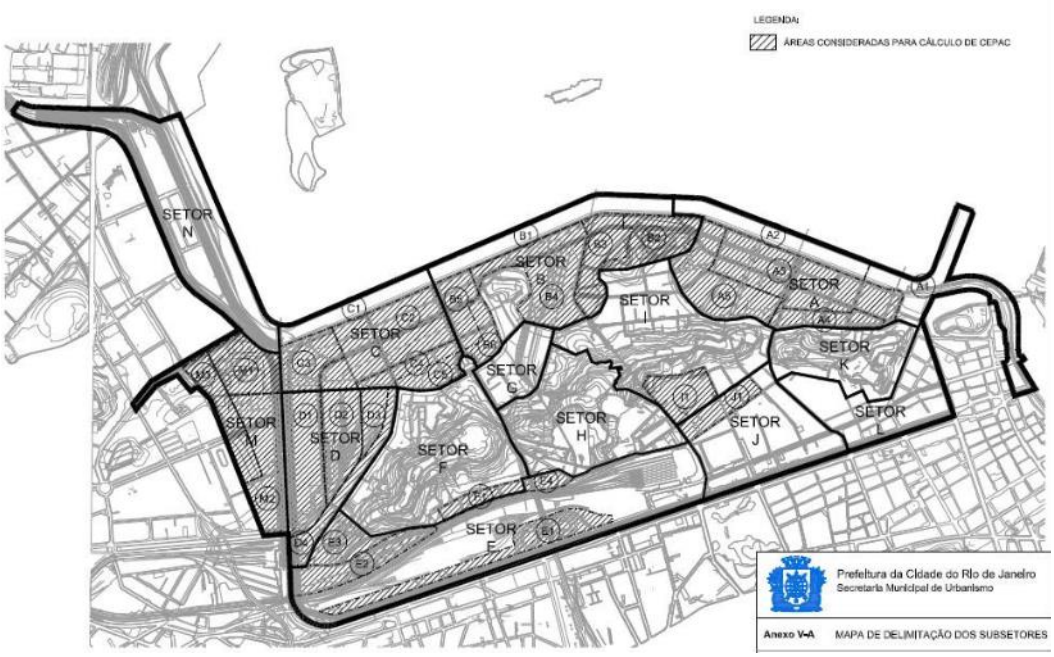


Figure 3 - Map of the intervention area divided into CEPACs sectors. Source: Amsler (2011).

With a comprehensive program to improve infrastructure and enhance the access to amenities, the city plans repurpose the Porto Maravilha's area into a ZUM - Zona de Uso Misto -, an urban redevelopment district zoned for mixed-use projects.

The area delimited by the project was destined to different uses – residential, commercial and retail, services and light industrial -, as shown in the following figure.

Figure 4 - Area and uses of Porto Maravilha project. Source: Amsler (2011).

Different sectors were created in the area of urban operation - CEPAC, for studies and projects with different intervention capacities in order to stimulate new development buildings in the region. Each zoning has its specific uses and potential built-area according to the CEPAC's. Figure 5 shows the division of the respective sectors. Through these quantitative construction data, it is possible to quantify the population density in the area in the project as a whole.

Figure 5 - CEPAC sectors. Source: Porto Maravilha, 2020.

The following table presents an overview of the economic and spatial estimative of the project as a "global reference" in the phase of pre-implementation, as well as some expected forecasting. For instance, the 22,000 inhabitants by 2011were expected to become 100,000 by the end of 2021.

Table 1 - Key aspects of the Porto Maravilha. Source: Porto Maravilha (2020)

Costs	Estimated total cost of urban interventions	R$ 8 billion (US$ 5.1 Billion)
	Estimated Total Value of Private Development	R$ 40 Billion (US$ 25,6 Billion)
Land Use	Total Land Area of Urban Interventions	5,000,000 square meters
	Total Potential Buildable Area	4,089,502 square meters
Density	Population by 2011	22,000
	Population Planed by 2021	100,000
Time Frame	Duration of Public Intervention	6 years
	Total Development Duration (Public and Private)	30 years
Costs	Estimated total cost of urban interventions	R$ 8 billion (US$ 5.1 Billion)
	Estimated Total Value of Private Development	R$ 40 Billion (US$ 25,6 Billion)
Ownership	Current Ownership of Developable Land	62% Federal, 6% State, 6% City, 25% Private

Being part of a large urban project, the Urban Operation Consortium of Porto Maravilha has brought several urban changes since its implementation aimed to host the mega events in 2014 and 2016 in Rio de Janeiro. Strongly focused in accessibility improvements as a part of the large urban revitalization project, the transformations in the transport system included:

- Demolition of an arterial roadway (Perimetral Via)
- Implementation of a Binary and Expressway
- Construction of tunnels and cycleways
- Implementation of Teleferic
- Bus Rapid Transit (BRT)
- Light Rail Transit (LRT)

Transformation in transport infrastructure enhancing the region in terms of accessibility and mobility. Among the spatial changes, the implementation of the LRT was one of the transformation vehicles in the urban structure in recent years. In addition to improving local access to public transport to the region, the implementation of the LRT should enhance the regional accessibility by integrating the Airport, Bus Station (*Rodoviária*) and the remaining transport modes. The following figure presents an overview of the LRT network as well as the location of the chosen LRT station covered by this study. The LRT implementation process will be more detailed in the next chapter four which presents the study area.

Figure 6 - Map of the LRT network and the stations to be analyzed.

3.2. ANALYSIS METHOD

Understanding how the performance took place in the entire urban intervention encompassed by the Porto Maravilha urban regeneration project, we can understand the transformations that occurred in specific locations within this area, namely in the LRT stations' surroundings. Accordingly, the Porto Maravilha performance will be used as a "reference" to evaluate the indicators considered in this study (density and mixed uses) to assess whether the performance was good or bad (i.e., if there was an increase in the resident population and/or an increase in diversity of uses, for example).

In order to understand the impact of the deployment of the transport system – particularly concerning the implementation of Light Rail Transit (LRT) in the urban structure, this study analyze the transformations occurred in land use system since the implementation of the *Carioca's LRT*, particularly in the following stations:

a) Vila Olímpica;

b) Santo Cristo;

c) Harmonia.

The study areas were chosen due to their capacity to offer the characteristics present in the region. In the process of defining the stations to be selected for analysis, their insertion in the various population centers, housing, commercial, industrial and others was considered. Although one of the main objectives of the LRT project was to attract more people (and investments) to these areas – which were expected to be valorized after the implementation -, such stations are located in areas occupied by most vulnerable population.

Given their strategic locations, the stations have close relations with points of high capacity of population density increases: proximity to the port region that is being revitalized, proximity to empty or abandoned areas that can be used for the deployment of new equipment and services, as well as proximity to traditional residential areas with low occupancy.

As to access public transport stations people need to walk to or from the LRT stations, we must consider a feasible distance so the choice for such transport becomes competitive. Some studies in this field consider a walking distance within 500 meters. As so, the study area definition considered a 500m radius from the reference point (represented by the three stations) considering the road network distance. The analysis thus focuses on the destination locations (land use plots) accessible within this distance threshold. The following maps present the 500-meters route-distance from each LRT station:

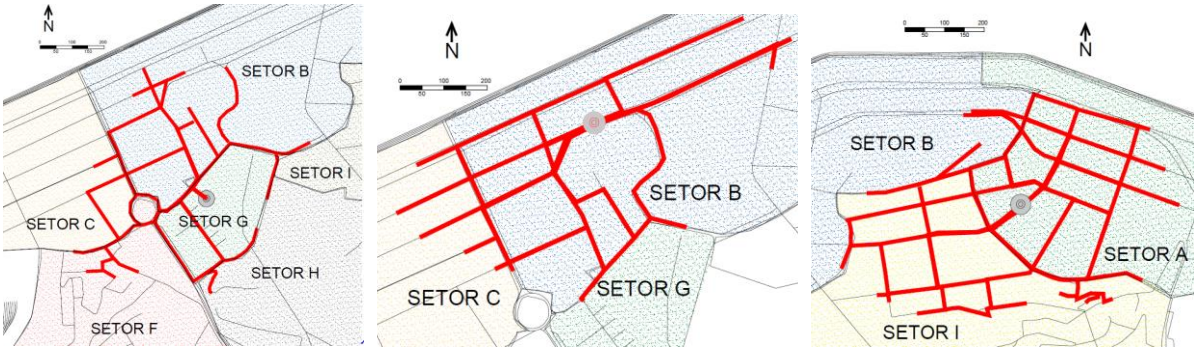


Figure 7 - 500m distance from the reference point - Vila Olímpica, Santo Cristo and Harmonia LRT stations.

In order to understand the direct impact of the LRT deployment in the aforementioned stations, the analysis also included data in a given location outside the LRT influence area of the light transit infrastructure.

The location was chosen due to the fact that, although belonging to the Porto Maravilha's intervention area, it represents a picture of the urban changes concerning density and mixed uses in an environmental context not directly affected by the LRT deployment, allowing a comparison of the indicators in both situations – with and without a new transit infrastructure.

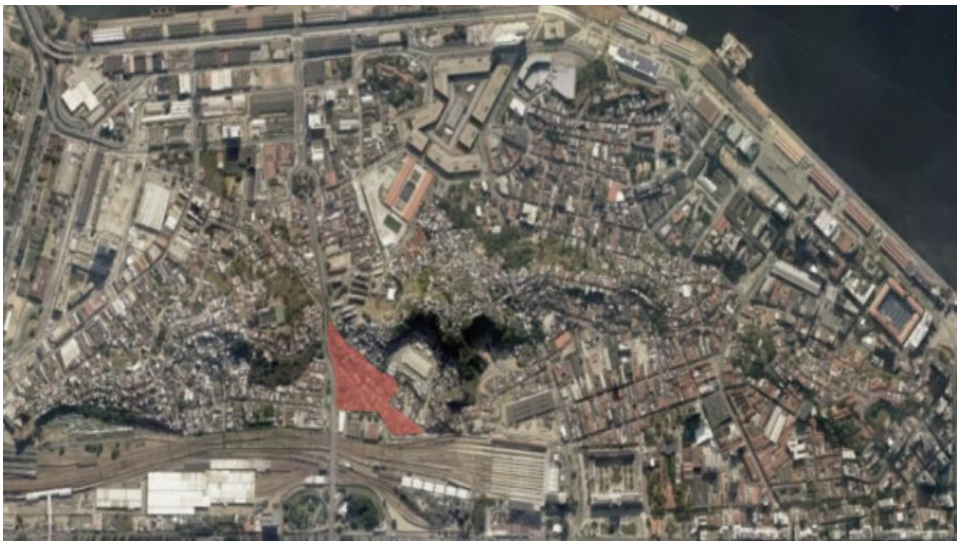


Figure 8 - Area belonging the Porto Maravilha region but outside the LRT influence area.

The evaluation on the land use impacts before and after the implementation thus consists of analyzing the study areas with a time frame approach – from 2011 to 2020. The analysis then focuses on the transformations in the land use system in the pre- and post-implementation of the LRT stations, comparing the characteristics in the areas around the stations in the current decade in quantitative terms. The land use characteristics covered in this study comprises the a) population density and b) land use mix or diversity.

The primary quantitative method of data collection was carried out through a process of measuring, ranking, categorizing, identifying patterns and making generalizations. In that way, this study aims to produce generalizable knowledge about the urban impacts of LRT, although based on specific study case in Rio de Janeiro. With the intention to be a valid research, it was required a carefully designed study, and it was necessary to find representatives samples, controlling the variables, according to what was found in different studies and researches.

This quantitative method used numerical assignments for the results. For the analyzed questions numerical results were assigned and investigated so that all available data could be transformed into

statistics. In this way, this investigation, through quantitative methodology, required an analytical understanding of the statistical data.

3.3. ANALYSIS INDICATORS

3.3.1. POPULATION DENSITY

The data of land-use occupation resort to maps prepared with data collected before and after the deployment of LRT network. For the demarcation of the constructions in the pre-implementation phase, an image dated January 3, 2010 was used as a reference base, from Google Earth. The demarcation of the existing constructions was based on an image from Google Earth dated March 27, 2020.

In the density map, all existing constructions were demarcated within the analyzed areas, differentiating by residential and non-residential buildings. The method to estimating population is based on the methodology applied by the Porto Maravilha Urban Operation[2] according to the built capacity of each type of land occupation. Our study also quantifies each typology in area, use and number of pavements to estimate the population density of each LRT station through the capacity index showed below.

Table 2 – Capacity Index. Source: Porto Maravilha (2020).

	Types of use	square meter / person
1	Low and medium standard horizontal residence	30.00
2	Commerce and horizontal service	50.00
3	Vertical trade and service	12.50
4	Industry	50.00
5	Warehouses and depots	50.00

From the existing calculable built areas in the Urban Operation CEPAC sectors (considering only the sectors of our research), it was possible to estimate the amount of the resident population in the analyzed areas before and after the time-period of 10 years (from 2010 to 2020).

The areas and uses were estimated based on the Rio de Janeiro City Hall cadastral plan for the year 2001. The estimate population represents the capacity of the buildings to house the population in the period before and after the implementation of the project, obtained through the computable built area.

The population densities were analyzed considering two different groups according to their sectors:

[2] Estimated population based on the potential for construction CEPACs sectors. Source: Porto Maravilha (2020).

- Group 1 – sectors 1 - F, G, H, I and K – located in the south part of the region;
- Group 2 – sectors A, B, C, D – located in waterfront areas.

3.3.2. LAND USE MIX

The analysis of this factor regards the main land uses that compose the diversity of a given place. Were defined as study variables and demarcated in the maps the uses: residential, commercial, institutional and recreational areas.

The maps were prepared also considering the two moments, before and after the implementation of the LRT system, the analysis was made using the comparative method with the quantitative analysis of each specific use.

3.3.3. ANALYSIS OF THE POPULATION GROUPS

The study also analyzes the profile of population using the LRT service (users) in comparison to the profile of population living in the surrounding of the transit stations.

3.4. DATA SOURCE

Data collection process considered different sources as follows.

a) IBGE

The data on population used the available information by the Brazilian statistic institute (IBGE – Instituto Brasileiro de Geografia e Estatística) from the last two available census: 2001 and 2011. We understand that, although the analysis does not cover the changes from the last decade since the LRT implementation (from 2011 to 2021), it shows the population change in a scenario before such structural change.

b) IPP

In order to bridge the gap on the IBGE data covering the current decade (2011 to 2021), the data available by the Municipal Urbanism Institute Pereira Passos (IPP) were used. Such data source uses the same administrative divisions used by the IBGE source, allowing a direct comparison between the two sources.

c) CEPAC

The information regarding the population using statistic estimation was collected from data on the areas built and their uses during execution and available in the sectors of Urban Operation - CEPAC.

The quantification methodology used by CEPAC to estimate the existing population in the total area of LRT deployment was used in the global area of the Porto Maravilha project, in the surroundings of the LRT stations under investigation and in the area outside the influence of the transit infrastructure.

4
CASE STUDY

This chapter presents the case study of pre- and post- implementation of the Rio de Janeiro LRT and is organized as follows. The first section presents the historical context of Porto Maravilha redevelopment urban project, and details the implementation process of its LRT system. The second section (4.2) presents the analysis of the land use factors in the moment preceding the project, followed by the post implementation analysis (4.3). The last section brings an additional analysis in the area belonging Porto Maravilha's region but outside the influence area (4.4).

4.1. PORTO MARAVILHA'S HISTORICAL CONTEXT

The metropolitan regions of several Latin American cities, including the city of Rio de Janeiro, have been experiencing major problems in their transit since the 20th century, with an impact also on the quality of life, the supply of jobs, the ability to travel, the supply of leisure and the process of increasing segregation and concentration of resources. At the beginning of the 21st century, the city of Rio de Janeiro chose, as one of the strategies to solve this challenge, the improvement of mobility through the implementation of LRT, as an alternative to medium size public transport.

During the first decade of the 2000s, the city of Rio de Janeiro received large investments in the area of urban infrastructure, particularly in the public transport sector, due to the major international events planned in the city, for the years 2014 and 2016. Public-private partnerships marked this moment, one of the main investments was the revitalization of the Port Zone of Rio - Porto Maravilha -, with the implementation of the LRT in the central region of the city. As said in the previous chapter, this project was conceived as part of a project with a larger scale of urban intervention, with the objective of revitalizing and reordering the center of the city, with associated projects in various sectors.

When referring to the central region of the City of Rio de Janeiro, before the investments for the big events, it was exclusively composed of the downtown neighborhood and some other regions such as Lapa and Cidade Nova. However, this region underwent an enlargement, after the inauguration of the LRT Lines and in conjunction with the developments in the Port Zone, now including areas such as: Gamboa, Saúde, Santo Cristo, as well as the consolidation of other areas such as Cidade Nova, São Cristóvão and Caju through their integration with demographic flows.

> *"The formation of the centre can be understood as the convergence point of a large part of the population that moves through its area on a daily basis, or even that the centre exists because of the large number of commerce and services present, or even that it constitutes an administrative centre" (IBID, 2013, p. 8).*

The demarcation of the central region and its conceptualization should be analyzed, considering the need to associate the concepts of centrality and accessibility. *"Thus, the central area emerged as a result of the centralization process, where accessibility and other factors addressed became preponderant in the construction and definition of this concept"* (Gluszevicz, 2013 p. 9). The current borderline features for the demarcation of the new central region of Rio de Janeiro are now associated with: verticalization; commercial activities such as: bars and stores; cultural activities, nightlife, the inauguration of attractive facilities such as museums and aquariums, in addition to the valorization of plots and changes in legislation and zoning.

Our object of study is also seen as a new modal of transport with possibilities to create integration to the existing modal, and to articulate the other demographic poles of the city. The inclusion to the tariff systems of the city - the "Bilhete Único Carioca" and the "Rio Card" - also allowed the flexibility and integration of the itineraries. The concept of a fully integrated network (Grotta, 2005, p. 205.), characteristic of well-developed transport systems, in which several modes of transport are available and integrated, was one of the premises when defining some origins and destinations of the proposed lines.

Thus, the initial proposal for the layout of the LRT lines in the city of Rio de Janeiro, had integrated the various modes of transport and increased the access of peripheral regions less favored by the transport infrastructure. Following the direction of the International Airport António Carlos Jobim - Galeão and on the way through neighborhoods such as Caju, and also through areas with large demands of demographic flows already established with the university and manufacturing centers and seeking connections with others planned lines of BRT (Bus Rapid Transit). Unfortunately, this initial project, with a strong capacity for territorial integration, was abandoned. Instead, another project was implemented, which was restricted to the more central region, being limited to an area that already had a greater offer of road and transport infrastructure. This redirection of decision-making to the definition of the route can be understood, due to the format of the public-private partnership model, selected for the realization of this initiative, which by very specific characteristics, does not compromise with

interests in development and social justice, but with the rapid financial return of its private investments and guarantee of profit to investors.

The implementation cost R$ 1.157 billion, of which R$ 532 million with federal resources from the Growth Acceleration Program - *Programa de Aceleração do Crescimento* (PAC) of Mobility, and R$ 625 million made possible through a public-private partnership (PPP) of the City Hall of Rio (EDITAL, 2012; CONTRACT, 2012). The investment in infrastructure in areas considered to be peripheral and its integration with the centrality, as observed in several sites in the port area, allows for greater horizontal incorporation of the city and its residents. Unfortunately, the investment model for the implementation of the LRT, which is part of Porto Maravilha project, was conceived as a public-private partnership - PPP, and governed by guidelines that are more in line with private capital regulations than with the commitment to social and civilizing progress. Thus, most of the associated developments are linked to real estate development in the areas along the LRT, with approved private initiative projects for new commercial buildings and international hotels.

4.1.1. THE IMPLEMENTATION OF THE 'CARIOCA'S LRT'

Inaugurated in June 2016, with a total extension of 28 km, the first stage for Rio's LRT was planned to connect the existing transport modes in the central region and Port zone – boats (barcas), subway, train, bus, bus station, airport, cable car, cruise ship terminal and with the future connections of BRT Transbrasil (BIRTH, 2017, p. 110). This possibility of connections between the several public transport systems, allows the distribution of passengers in the regions that compose the central area of the city. By the conclusion of the entire Carioca LRT project will have a transport capacity of 300 thousand people per day.

The LRT is a sustainable model of transport, powered by electricity, captured by a third central line of rails, which does not require the use of overhead wiring. The carioca's LRT project provided a total of 32 trains with the following characteristics: 3.82 m high, 44 m long, 2.65 m wide and with a capacity for 420 passengers. Another important feature is that the trains are bi-directional and composed of 7 articulated modules.

The current route of the LRT connecting the Port region to the city Centre, provides the integration with the airport, the boats, the bus station; the central train station; the Providência's cable car and with the subway network.

The implementation of the project occurred in two stages. The first stage consisted in the implementation of the route defined as the Section *Vila da Mídia - Santo Cristo - Praça Mauá – Cinelândia*. The second stage, with a longer deadline forecast for its delivery, had its route defined as the Section *Central - Barcas, Santo Cristo - America - Central - Candelária, America - Vila de Mídia and Barcas - Santos Dumont*.

The following figures present the LRT network considering the two stages of implementation and the current route in operation. In both cases, our LRT stations under investigation are highlighted.

Figure 9 - LRT Carioca implementation phases. Source: Porto Maravilha, 2020.

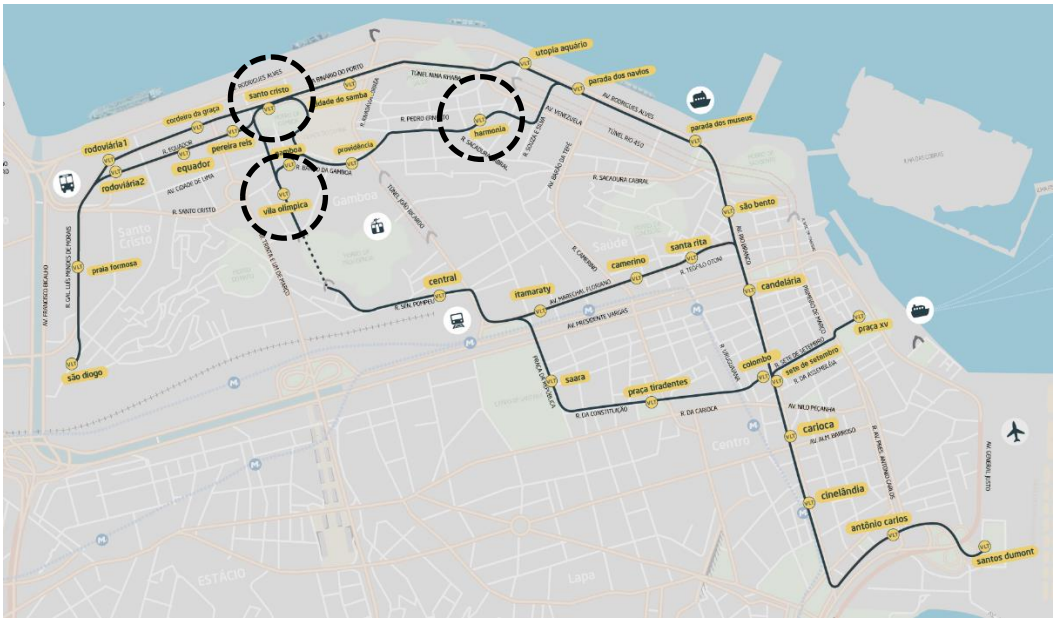


Figure 10 - Current route of the LRT. Source: Porto Maravilha, 2020.

Currently there are three lines in operation, with different origin, route and destination, although there are overlaps in some stretches. We present here the details of the lines with identification of some reference points and interest locations:

The Line 1 started operating in June 2016, with origin at Santos Dumont Airport to the region of Novo Rio Bus Station, connecting also the downtown roads, the entire extension of Avenida Rio Branco, part of Orla Conde and the binary of the Port. The total extension of this route total 6.4 km with 20 stops. The line also provides access to subway lines 1 and 2, to the cable car, to bus terminals, to the Airport, Bus Station and the cruise terminal Pier Mauá.

This line was the first one to be implemented and crosses the Line 2 in the Sete de Setembro/Colombo station, sharing from this point the same route along seven more LRT stations until the west-side in the Santo Cristo neighborhood.

The Line 2 started operating in February 2017, connecting the Praça XV to the region of Rodoviária Novo Rio, covering roads in downtown such as Rua Sete de Setembro, Praça da República, Rua Senador Pompeu, Túnel da Marítima and the Port binary. The total extension of the route total 5.2 km along 20 stops. The line also allows access to subway lines 1 and 2, to the boats (Barcas da Praça XV) terminal, to 5 SuperVia train branches, to the Providência cable car and the municipal bus terminals Procópio Ferreira, Américo Fontenelle and Padre Henrique Otte, as well as to the intermunicipal bus station.

Finally, the Line 3 has been in tests by November 2018 and has its effective operation in October 2019, connecting Santos Dumont Airport and bound for Central do Brasil, along downtown roads such as part of Avenida Rio Branco and Avenida Marechal Floriano. This stretch has a total route of 4.0 km, which mostly shares the route of Line 1. The line has 10 stations, being 6 stops shared with Line 1 and two stops shared with Line 2.

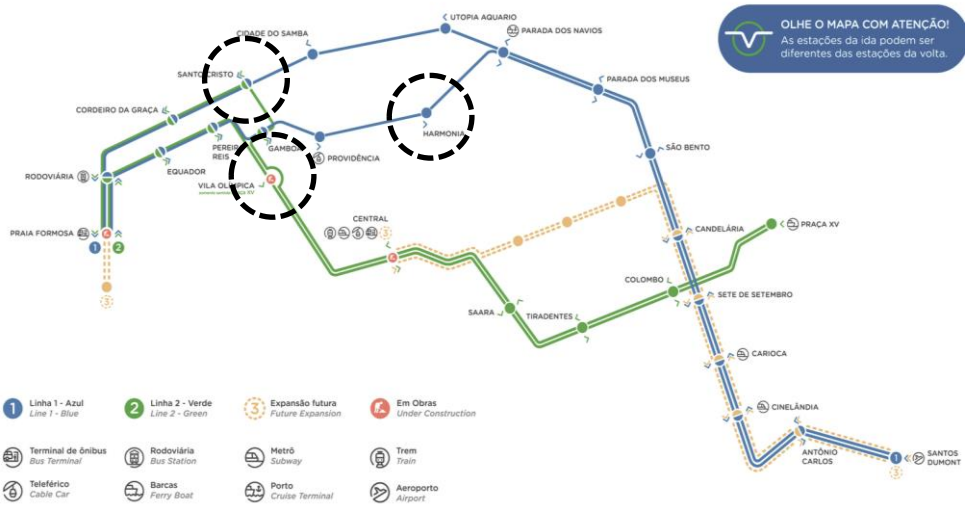


Figure 11 - Official map of LRT. Source: Porto Maravilha, 2020.

Some points of interest and "reference" places along the three lines are presented as follows.

- Line 1: Santos Dumont Airport, the Museum of Modern Art of Rio de Janeiro, Cinelândia, the Municipal Theater, the National Library, the National Museum of Fine Arts, Largo da Carioca, the Candelária Church, Mauá Square, the Museum of Tomorrow, the Museum of Art of Rio, Orla Conde, AquaRio, the Harmony Square, the City of Samba and the Novo Rio Bus Station.

- Line 2: XV Square, the Count's Edge, the Imperial Palace, the Arco do Teles, the Church of Nossa Senhora do Monte do Carmo, the Tiradentes Palace, the Confeitaria Colombo, the Real Gabinete Português de Leitura, the João Caetano Theater, the Tiradentes Square, the Mackenzie Rio Presbyterian College, the CIEE, the SAARA, the Campo de Santana, the Duque de Caxias Palace, the Central Station, the Samba City and the Novo Rio Bus Station.

- Line 3: Santos Dumont Airport, the Museum of Modern Art of Rio de Janeiro, Cinelândia, the Municipal Theater, the National Library, the National Museum of Fine Arts, Largo da Carioca, the Church of Candelária, the Church of Santa Rita de Cássia, the campus Centro do Colégio Pedro II, the Light Cultural Center, the Itamaraty Palace, the Duke of Caxias Palace and the Central Station of Brazil.

Regarding the three LRT station under analysis (highlighted in the previous figure), it is important to point out that Vila Olímpica and Santo Cristo stations, implemented in the first stage (2016), belong to the route of Line 1 (green). Harmonia station, which implementation has taken place in the second stage (2017) belongs to the Line 2 (blue). Santo Cristo is the station that belongs both to lines 1 and 2.

4.2. PRE-IMPLEMENTATION FRAMEWORK

In this section, we develop the analysis of the land-use indicators – population density and land use mix - in the period before the implementation of the LRT network.

The analysis starts by estimating the global area of Porto Maravilha redevelopment project, with regard to the mandatory neighborhoods comprised by this area, namely Santo Cristo, Gamboa and Saúde. Such local-administrative boundaries represent major part of Porto Maravilha overall area. The following section (4.3.2) presents the analysis of the LRT surroundings of the Santo Cristo, Vila Olímpica and Harmonia transit stations, and concludes with the comparison of such parameters to an area outside the LRT influence area.

4.2.1. Porto Maravilha (Santo Cristo, Gamboa and Saúde Neighbourhoods)

4.2.1.1. Density

According to the demographic data collected from IBGE (2000 and 2010) in the area comprised by the Porto Maravilha project – Santo Cristo, Gamboa and Saúde neighborhoods - were about 22 294 inhabitants by 2000 and 28 187 inhabitants by 2010. As shows the graph below, these numbers represent a population growth of 26% from 2000 to 2010.

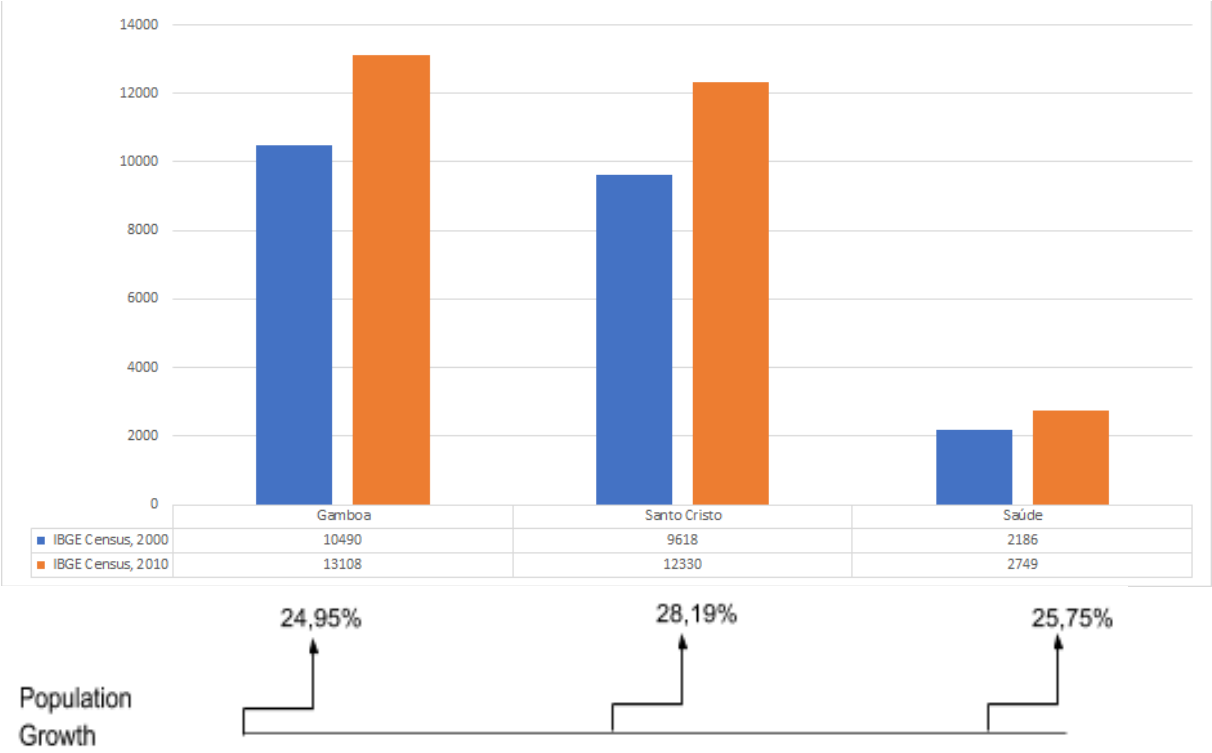


Figure 12 - Population growth in Gamboa, Santo Cristo and Saúde. Source: IBGE (2000-2010).

Regarding each neighborhood separately, it can be noticed that Santo Cristo presented bigger increase compared with the other two by 2010.

From the CEPAC[3] data, the population information allowed to quantify the population density. The division of distinct sectors by the urban operation defines the maximum construction parameters for studies and projects with different intervention capacities, as explained in the methodology section. The population densities were analyzed considering the two different groups: Group 1 – sectors with higher population density and Group 2 with lower population density, based on the construction capacity index.

[3] It must be noticed that the delimitated area by the CEPAC urban operation does not coincide with the census districts, but allows an independent analysis.

Before the project, the population density of the two different groups impacted by the LRT is analyzed:

- Group 1 - F, G, H, I and K sectors - comprising of higher population density indexes
- Group 2 – A, B, C, D sectors - with lower population density indexes

Sectors belonging to Group 1 represent areas with highest housing densities and related to the main traditional communities of this region: Santo Cristo, Gamboa and Saúde. In turn, Group 2 comprises of the areas with lowest housing densities, related to the Port's activities, and most of its existing constructions are abandoned sheds or industrial installations.

Located in the south part of the intervention area, the Group 1 (sectors F, G, H, I and K) are the areas with the highest housing densities, related to the main traditional communities of this region: Santo Cristo, Gamboa and Saúde. The coast line however is occupied by typology of Group 2 (sectors A, B, C and D), showing the areas with the lowest housing densities, related to the Port's activities, with most of the existing buildings as abandoned sheds or industrial installations.

From the existing calculable built areas in the Urban Operation sectors (considering only the sectors of our research, in the period prior to the deployment of infrastructure), we obtained the resident and floating population in these areas as shows the following table.

Table 3 - Construction area per type of occupation by CEPAC sector.

	CEPAC Sector	**Built Area (M^2)**	**Residential**		**Non-Residential**	
			Built Area	%	Built Area	%
Group 1	F	230 104,70	142 569,23	39,30	87 535,47	17,91
	G	23 834,52	15 675,14	4,20	8 159,37	1,67
	H	180 563,45	82 406,00	22,70	98 157,45	20,09
	I	291 154,93	88 890,00	24,70	202 264,93	41,39
	K	125 623,20	33 117,00	9,10	92 506,20	18,93
	TOTAL	**851 280,80**	**362 657,37**	**42,60**	**488 623,42**	**57,40**
Group 2	A	559 856,00	657,00	4,46	559 199,00	46,31
	B	323 508,64	13 626,64	92,52	309 882,00	25,66
	C	201 931,00	-	-	219 931,00	18,22
	D	118 930,00	444,00	3,02	118 486,00	9,81
	TOTAL	**1 222 225,00**	**14 727,64**	**1,21**	**1 207 498,00**	**98,79**

From the Capacity Index table which estimates the population according to the constructed area, was possible to simulate the capacity of the buildings to house the population by 2001 in sectors in Group 1 and 2. The amount of the resident population at this time was estimated in order to obtain an initial comparative reference for the analysis of the increase in density in these same areas in the decade ahead.

The following table presents the results of such analysis.

Table 4 - Population per type of occupation by CEPAC sector.

	CEPAC Sector	Total Population	Residential		Non-Residential	
			Population	%	Population	%
Group 1	F	6 503	4 752	73,1	1 751	26,9
	G	686	523	76,2	163	23,8
	H	4 710	2 747	58,3	1 963	41,7
	I	7 008	2 963	42,3	4 045	57,7
	K	2 954	1 104	37,4	1 850	62,6
	TOTAL	**21 861**	**12 089**	**55,3**	**9 772**	**44,7**
Group 2	A	11 206	22	0,2	11 184	99,8
	B	6 652	454	6,8	6 198	93,2
	C	17 594	-	-	17 594	100
	D	2 385	15	0,6	2 370	99,4
	TOTAL	**37 837**	**491**	**1,3**	**37 346**	**98,7**

Given the underutilization of these areas because unused buildings in Group 1 sectors, we apply a mitigation factor[4] considering that almost 65% of these areas are abandoned. The population considered for simulation purposes total 7.652 people (21 861 total population X 0.35 mitigation factor) in the sectors of Group 1.

Considering the Group 2, the underutilization of these areas because of abandoned buildings requires a mitigation factor[5] considering that almost 75% of these areas are unused. Thus, the population considered for simulation purposes total 9.459 people (37 837 total population X 0.25 mitigation factor) in the sectors of Group 2.

As a result, it is possible to account for a total of 17.111 people in the groups analyzed. Considering only the residents, 7.652 in the Group 1 (44,7%), area characterized as a more traditional residential occupation with a high level of degradation and abandonment. 9.459 people were found in the Group 2 (55,3%), area characterized mostly by abandoned buildings related to the functioning of the Port.

4.3.1.2. Land Use Mix

The picture of the distribution of urban space occupation is the consequence of many factors, such as: the form and typologies of urban land occupation and use. Where such occupation can be fostered by the real estate market or by spontaneous occupation, also some structural factors, such as the road system, infrastructure networks and deployments of transport modes, contribute to directing the axes of

[4] The percentages were based on the forecasting method used by the Consortium Operation of Porto Maravilha to calculate the estimated population face the potential for construction CEPACs' sectors. Source: Porto Maravilha (2020).
[5] Same as above.

occupation and their characteristics. There are still other factors that can influence urban land occupation, such as: topography, hydrography, existence of equipment and services.

The area comprised by the Porto Maravilha region is characterized by a diversity of typology and occupation, as a result of its urban evolution history. The buildings are distributed in residence and warehouse uses.

This area was also characterized by a diversity of building typologies, derived from a long historical process of occupation of this region. The area is divided into two occupation patterns in the upper and lower parts. In the upper part are located the hills and have colonial architectural features with narrow and deep lots with houses without front retreat and with one or two floors in general. In the lower part, created from landfills at the beginning of the 20th century is found larger urban blocks to support the Port activities. They have larger lots and were mostly occupied by warehouses, sheds and industrial facilities as results of the demands of the Port of Rio de Janeiro.

Inserted in the perimeter of the Consortium Urban Operation of the Port of Rio de Janeiro Region the area has social and urban planning diversities, where the coexistence of irregular occupations (favelas) in the consolidated neighborhoods are identified. There are also other different realities: risk areas/ urbanized plazas, streets with sewage systems and piped water/streets without sewage system and exposed.

From the previous table 3, is also possible to distinguish that the Group 2 although presented higher population in absolute terms, the typology found is mostly abandoned buildings related to the Port functions characterized by a low-density area. In the overall, Group 2 is substantially composed by non-residential with industrial use. Group 1 in turn presented low number of people in an area characterized by traditional communities more equally distributed in residential (55%) and non-residential (45%) uses although with high abandonment level as well.

4.3.1.3. Population Profile

The individual's socio-economic characteristics reveal the profile of the population living in the Porto Maravilha region. Gender, age, educational level, social and economic situations by the pre-implementation phase according to IBGE's last census (2010) are as follows.

The population resident in the area is comprised of 48,47% of men users and 51,53% women. Among the resident population, the age-groups are comprised of 39,19% under 24 years old; 18,75% has between 25 - 34 years old; 15,08% has 35 - 44 years old; 9,90% has between 45 - 54 years old and 17,09% has over 56 years old. The educational level of the population is comprised of 2,63% aliterate; 21,24% has frequented the Elementary school; 51% the high school; 19,94% finished the secondary school and about 5,2% went to the University.

With respect to the social class, the census has showed that 88,69% of users belong to Class D/E, representing the most vulnerable group of population. 12,74% belongs to Cass C, 1,57% to Class B and no Class A (highest income group) was found in this region.

The economic situation of the LRT users presents an average income of R$ 800.00 reais, the minimum income/ salary.

4.3.2. LRT STATIONS' SURROUNDINGS

In this section, Population density and land use mix are analyzed in the pre-implementation phase, which express the situation within the areas in the three stations' surroundings – Vila Olímpica, Santo Cristo and Harmonia - before the LRT deployment.

Figure below presents the analysis on the type of buildings found in the LRT surrounding of each station under analysis. By distinguishing the land uses in this area by residential and non-residential, the analysis allows to calculate the area occupied of each building type to estimate the population based on CEPAC sectors

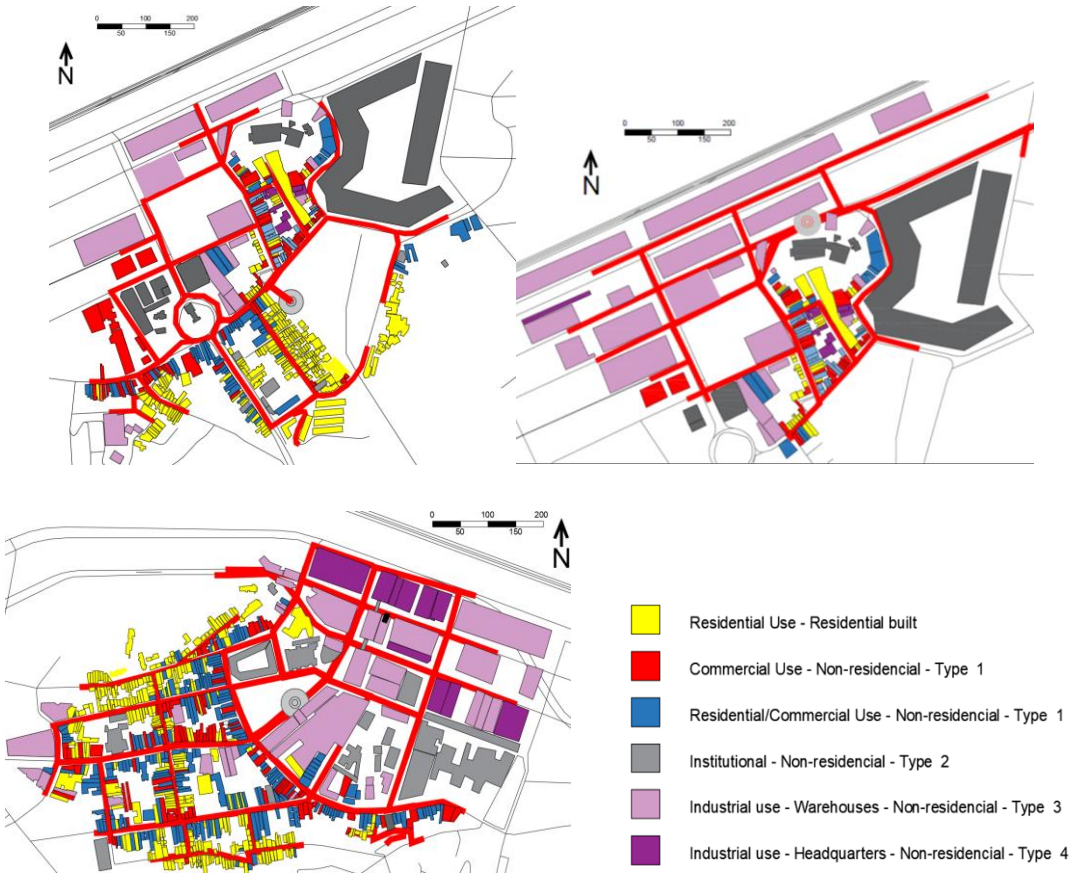


Figure 13 - Types of buildings in Vila Olímpica, Santo Cristo and Harmonia LRT stations.

The maps present the type of occupation divided into residential and non-residential uses. The non-residential areas are in turn divided into four building types according their function: Commercial and Residential/Commercial (Type 1); Institutional (Type 2); Industrial Warehouse use (Type 3); and Industrial Headquarters (Type 4).

The analysis also included the number of pavements (stores) of the buildings in the same LRT influence areas as shows the maps below.

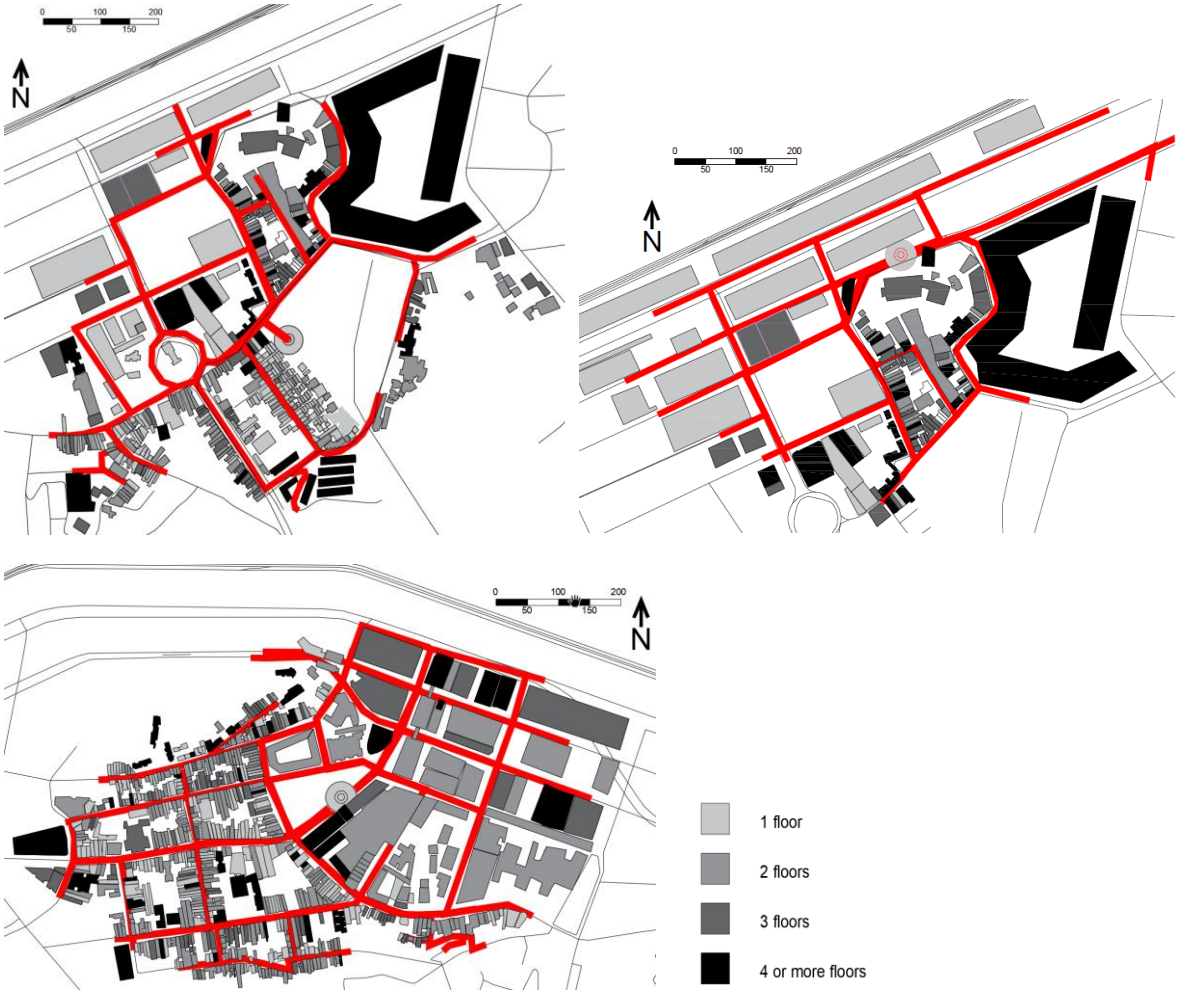


Figure 14 - N. of pavements in buildings in Vila Olímpica, Santo Cristo and Harmonia locations by 2010.

4.3.2.1. Population Density

When analyzing the mapping of the LRT stations in the study areas it can be noted that the choice of locations of the stations were distributed mostly in industrial areas with high abandonment building rates

and lower population densities. Great part of traditional residential areas with higher population density is not covered by the LRT system – or at least not within the 500-metre influence area.

It can be seen that one of the routes projected for the LRT lines, which is parallel route to the port, passed through large empty areas and abandoned warehouses. In the maps no major changes were identified in the square meters built, since the large projects planned in this area, such as hotels, company headquarters, commercial buildings and services were not constructed to the present date.

Using the same methodology used in the analysis of the global area of Porto Maravilha's project, the table below presents the construction area considering the use and type in each location – Vila Olímpica, Santo Cristo and Harmonia LRT stations -, obtained by the previous maps.

Table 5 - Construction area per type of occupation, in the influence area of LRT stations under analysis in 2010.

	Built Area (M^2)	**Residential**		**Non-Residential**				
		Built Area	%	Type 1	Type 2	Type 3	Type 4	%
Vila Olímpica	177 918	34 869	19,60	36 414	61 227	43 318	2 090	80,40
Santo Cristo	159 281	7 335	4,61	14 054	53 186	81 451	3 255	95,39
Harmonia	179 641	30 644	17,06	41 285	30 162	59 461	18 089	82,94

It can be noticed that the non-residential area is much higher than the total residential area in the three stations, varying from 80% to 95%. The residential areas represent less than 20% in the three cases.

Regarding the non-residential areas, the analysis showed that Vila Olímpica and Santo Cristo present a large amount of institutional and industrial areas (type 2 and 3). Showing the bigger difference between residential and non-residential areas, Santo Cristo station has also showed a large amount of industrial area with high level of building degradation and abandonment. Harmonia station was found to have more occupation by commercial and institutional areas - type 1 and type 2, as well as industrial type 3.

In order to quantify the population in non-residential areas - commercial, institutional and industrial -, we applied the mitigation factor in the building types with high abandonment and degradation conditions – type 3 and 4. The high level of abandonment in non-residential areas with industrial use, mitigation factor of 65% (0,35) was considered to get the estimated existing population in the three stations.

Table 6 – Estimated population per type of occupation, in the influence area of LRT stations under analysis.

	Total Population	**Residential**		**Non-Residential**				
		Population	%	Type 1	Type 2	Type 3	Type 4	%
Vila Olímpica	7 254	1 162	16,00	728	4 898	390	75	84,00
Santo Cristo	5 631	245	4,35	281	4 255	733	117	95,65
Harmonia	5 446	1 021	18,75	826	2 413	535	651	81,25
Total	18 331	2 428	13,24	-	-	-	-	86,76

The analysis on population showed that Vila Olímpica and Harmonia present higher population (16% and 18,75%) than in Santo Cristo (4,35%) in the pre-implementation phase.

With regard to the type of occupation by number of floors, the table below shows in each location the area occupied by different building pavements and densities.

Table 7 – Type of occupation by number of floors in the analyzed areas during the pre-implementation phase.

Pavements/Floors	Vila Olímpica		Santo Cristo		Harmonia	
	Area (M^2)	%	Area (M^2)	%	Area (M^2)	%
1	64 915	35,64	8 805	6,05	25 973	15,74
2	31 596	17,35	85 277	58,55	75 587	45,82
3	25 293	13,89	1 865	1,28	37 775	22,90
4 or more	60 323	33,12	49 705	34,13	25 643	15,54
Total	182 127	100	159 281	100	164 978	100

In general, all the stations' surrounding showed a low built density with only 34% of the buildings with 4 or more floors in Santo Cristo, 33% in Vila Olímpica and 15% in Harmonia. This result shows the higher built capacity in Vila Olímpica and Santo Cristo than in Harmonia station in the period before the implementation phase.

In **Vila Olímpica**, where about 67% of the buildings with up to 3 floors, the numbers reinforce the characteristics of the historical process of land occupation in this region, where we have the buildings with architectural characteristics of the colonial period and few floors. The buildings with four or more floors are basically contemporary constructions, such as the residential blocks of the Providencia hill and the City of Samba. Other buildings of this type also include headquarters of the companies focused on port and industrial activities.

In **Santo Cristo**, although the buildings with two floors representing 58%, this region also demonstrates the characteristic of low density of occupation, with about 65% of the buildings with up to 3 floors, expressing the historical process of occupation in this region. Such as presented in Vila Olímpica, the buildings with four or more floors are contemporary constructions. Other buildings of this type include commercial and multi-family housing buildings.

The analysis in **Harmonia** highlights even more the low occupancy density, with about 85% of buildings with up to 3 floors, of which 45% two-floors buildings. As in the other areas, the numbers reinforce characteristics of the historical process of land occupation in the Port region. Buildings with four or more floors are mostly commercial buildings, headquarters of companies and some multifamily housing buildings.

4.3.2.2. Land Use Mix

The mapping of the land use occupation also allows an analysis regarding the land use mix of the areas under study. The study areas (where the LRT of Rio de Janeiro was implemented) were characterized by a diversity of typology and occupation, resulting from the history of urban evolution in this region. The buildings are distributed in the space with residences and warehouses.

The table below presents the land use occupation of each station in the period before the implementation of the LRT infrastructure.

Table 8 - Land use occupation in the analyzed areas in the pre-implementation phase.

Land Use Occupation	Vila Olímpica		Santo Cristo		Harmonia	
	Area (M^2)	%	Area (M^2)	%	Area (M^2)	%
Residential	34 869	19,60	7 335	4,61	30 644	17,06
Commercial	166 666	9,37	5 318	3,34	13 601	7,57
Residential/Commercial	19 748	11,10	8 736	5,48	27 684	15,41
Institutional	61 227	34,41	53 186	33,39	30 162	16,79
Industrial – Warehouse	43 318	24,35	81 451	51,14	59 461	33,10
Industrial – Headquarters	2 090	1,17	3 255	2,04	18 089	10,07
Total	177 918	100	159 281	100	179 641	100

Analyzing the land occupation considering in **Vila Olímpica** location, it is possible to see that the use mix has different characteristics according to its geographical distribution and historical process of urban occupation. The industrial use with the warehouses near the port region reaches approximately 25% of the occupation, while the residential use stands out in the upper part of the region, where the traditional residential zone is found. There is a greater combination of uses, where traditional buildings are implanted along the highest flow paths, where commercial and residential/commercial uses are found.

The high percentage of institutional use stands out, with approximately 35% of urban occupation, due to the large dimensions of the Cidade do Samba building. Combining commercial and residential/commercial uses sum about 20% of the land occupation, however it is important to notice that a great part of these buildings is abandoned or in a bad state of conservation.

In **Santo Cristo**, the analysis shows the predominance of industrial use with the warehouses focused on port activities (51%). The different characteristics of the urban occupation are in accordance with its geographical distribution and historical process.

The residential, commercial and residential/commercial uses sum approximately 13% and are concentrated along the highest flow paths. Combining only commercial and residential/commercial uses add up to approximately 8% of the land occupation, however it should be noted that a large part of these

buildings is abandoned or in a poor state of conservation. Institutional use represents 33% of urban occupation due to the Cidade do Samba building.

Considering the **Harmonia** location, it is possible to see two different sectors, one with the predominance of industrial use in large lots, with warehouses concentrated in port activities and the other with the dispersion of uses in small lots, in accordance with their geographical distribution and historical process. Industrial use with warehouses and administrative headquarters of companies are close to the port region and reach approximately 43% of the occupation.

Summing residential, commercial and residential/commercial uses reach about 40% and are concentrated along the highest flow paths, although a great part of these buildings is abandoned or in poor condition. Residential use is distributed throughout the area, where an urban occupation from the colonial period is identified, with approximately 17% of the land occupation, covered by roads with small flows. Institutional use sums 16% of urban occupation, due to military and hospitals complexes.

4.3. POST-IMPLEMENTATION FRAMEWORK

Now, we develop the analysis of the land-use indicators – population density and land use mix - in the period after the implementation of the LRT network in 2016.

4.3.1. PORTO MARAVILHA (SANTO CRISTO, GAMBOA AND SAÚDE NEIGHBOURHOODS)

4.3.1.1. Population Density

The analysis on the population in the phase post-implementation in the area comprised by the Porto Maravilha project includes the data from IPP (2020). The available data shows that about 29 707 of inhabitants living in this region by 2020. The graph below shows that while in the decade 2000-2010 population growth was about 26%, the last decade showed a very discrete population growth of 5,4% from 2010 to 2020.

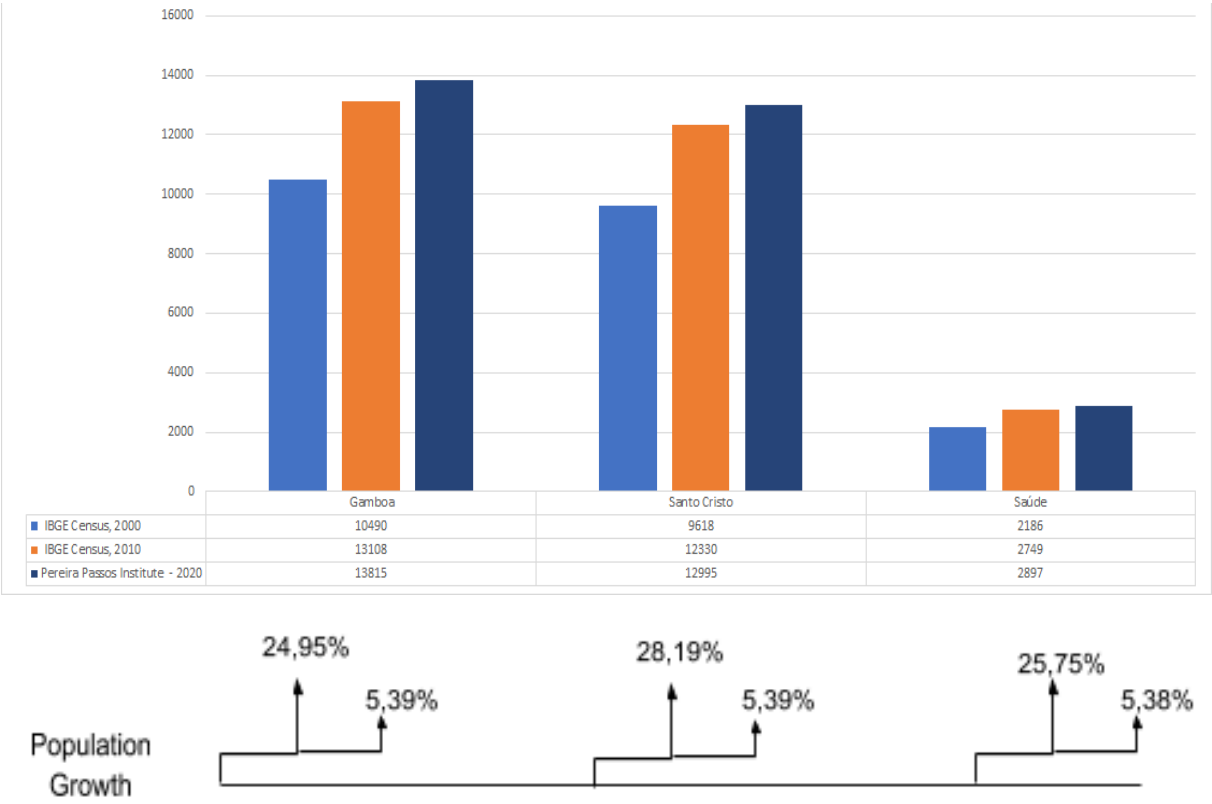


Figure 15 - Population growth in Gamboa, Santo Cristo and Saúde. Source: IBGE (2000-2010) and IPP (2020).

Regarding each neighborhood separately, it can be noticed that even Santo Cristo where which presented bigger increase compared with the other two by 2010, in the current decade however the population growth was similar with the total area of Porto Maravilha (about 5%).

Considering the Construction Potential introduced by the CEPACs, a population increase could be possible in the analyzed sectors from 17.111 people to an estimated total of 59.698 people, as shows the table below. This population increase did not take into account possible new constructions, but rather the use of existing constructions.

This estimative on population took into account the total possibility of occupation of existing buildings, considering that before the implementation of the projects for these areas. Given that 65% of the existing buildings were unoccupied with high levels of abandonment and consequent low occupation.

Table 9 - Population per type of occupation by CEPAC sector.

	CEPAC Sector	Total Population	Residential		Non-Residential	
			Population	%	Population	%
Group 1	F	6 503	4 752	73,1	1 751	26,9
	G	686	523	76,2	163	23,8
	H	4 710	2 747	58,3	1 963	41,7
	I	7 008	2 963	42,3	4 045	57,7

	K	2 954	1 104	37,4	1 850	62,6
Group 2	A	11 206	22	0,2	11 184	99,8
	B	6 652	454	6,8	6 198	93,2
	C	17 594	-	-	17 594	100
	D	2 385	15	0,6	2 370	99,4
Total		**59 698**	**12 580**	**21,1**	**47 118**	**78,9**

With the implementation of all the projects planned for the Port of Rio de Janeiro, including the structural works and private public investments, there would be an increase in population of around 300,000 inhabitants, among residential and commercial uses, in addition to the floating population.

The following premises were considered for the adoption of this densification projection:

- More use of available land, verticalized occupations and inclusion of institutional uses.
- Demarcation of areas propitious to great transformations of occupation because they are empty or abandoned, as well as the demarcation of areas with existing occupations with less conditions of transformation.
- New land parceling, with new land use and occupation regulations, which will allow greater incentives for new occupations with higher occupation coefficients.

It was predicted that within 15 years there would be a population increase in relation to that population of the order of 301.610 inhabitants, including the resident, user and floating population. This reality has not been confirmed due to the fact that most of the projects proposed for the areas aiming to increase commercial, institutional and residential construction and investments have not been implemented.

4.3.1.2. Mix Uses

The original project expected great transformations in land uses with the reconversion of areas before characterised by industrial uses and abandoned constructions into commercial and mixed (residential/commercial) areas. As already mentioned, great part of the large projects which would contribute to increase the mixed uses has not been implemented by the present sate, but there are some considerations do notice.

Considerable part of the “empty” or abandoned buildings were converted into commercial uses and institutional occupation, aimed to respond the mega sporting-event occurred in 2014 and 2016.

When analyzing the proximity of the LRT route in relation to the groups of sectors, it is noted that Group 2 benefiting better of this mode of transport, although presented low density and a high rate of abandoned buildings. Group 1 however is less covered by the LRT route, characterized by a greater distance between the LRT route and the traditional housing areas. Although the LRT lines does not cover this

group directly, the sectors remain within the LRT's area of influence, considering the 500-metre distance from the transit stations.

4.3.1.3. User Profile

With the objective of perceiving the characteristics of its passengers, a mobility survey[6] at the end of 2017 has collected the profile of LRT users by the concessionaire responsible for the LRT in Rio de Janeiro. Characteristics such as gender, age, schooling, residence, economic situation and motivation to use the LRT are presented as follows.

The gender of the passengers is comprised of 55% of men users and 45% women.

Regarding the age, the group that use the most the transit modal ranges from 25 – 44 years old (32%), followed by 35 – 44 years old (23%) and over 56 years. Users under 24 years old and 45 – 54 years old represent both 14%.

With respect to the social class, the survey has showed that 60% of users belong to Class B, 27% to Class C, and 11% of users belong to Class A (highest households). Only 2% of users belong to Classes D and E, the most vulnerable population groups.

The survey also showed 49% of the users with high education level (University), 42% has secondary level, 5% high school and 3% with elementary school. Illiteracy users represents 1% of this universe.

The economic situation of the LRT users presents an average income of R$ 6.157 reais, and the main reason to use such a transit modal is commuting (home-wok) purpose (68%).

4.3.2. LRT STATIONS' SURROUNDINGS

Based on the quantification of the square meters built of the building types we obtained the population variation from 2010 to 2020 was possible, showed by the maps below.

[6] Source: https://medium.com/mobilidade-carioca/para-quem-recebe-mais-de-r-6-mil-m%C3%AAs-vlt-%C3%A9-um-sucesso-39c2090a2c70 and http://www.eletromidia.com.br/assets/pdf/VLT_CARIOCA.pdf

Figure 16 - Vila Olímpica, Santo Cristo and Harmonia LRT stations' land use occupation in the post-implementation phase.

Allowing for an analysis of the verticalization (built density), the following maps present the number of floors in the existing buildings within the analyzed areas.

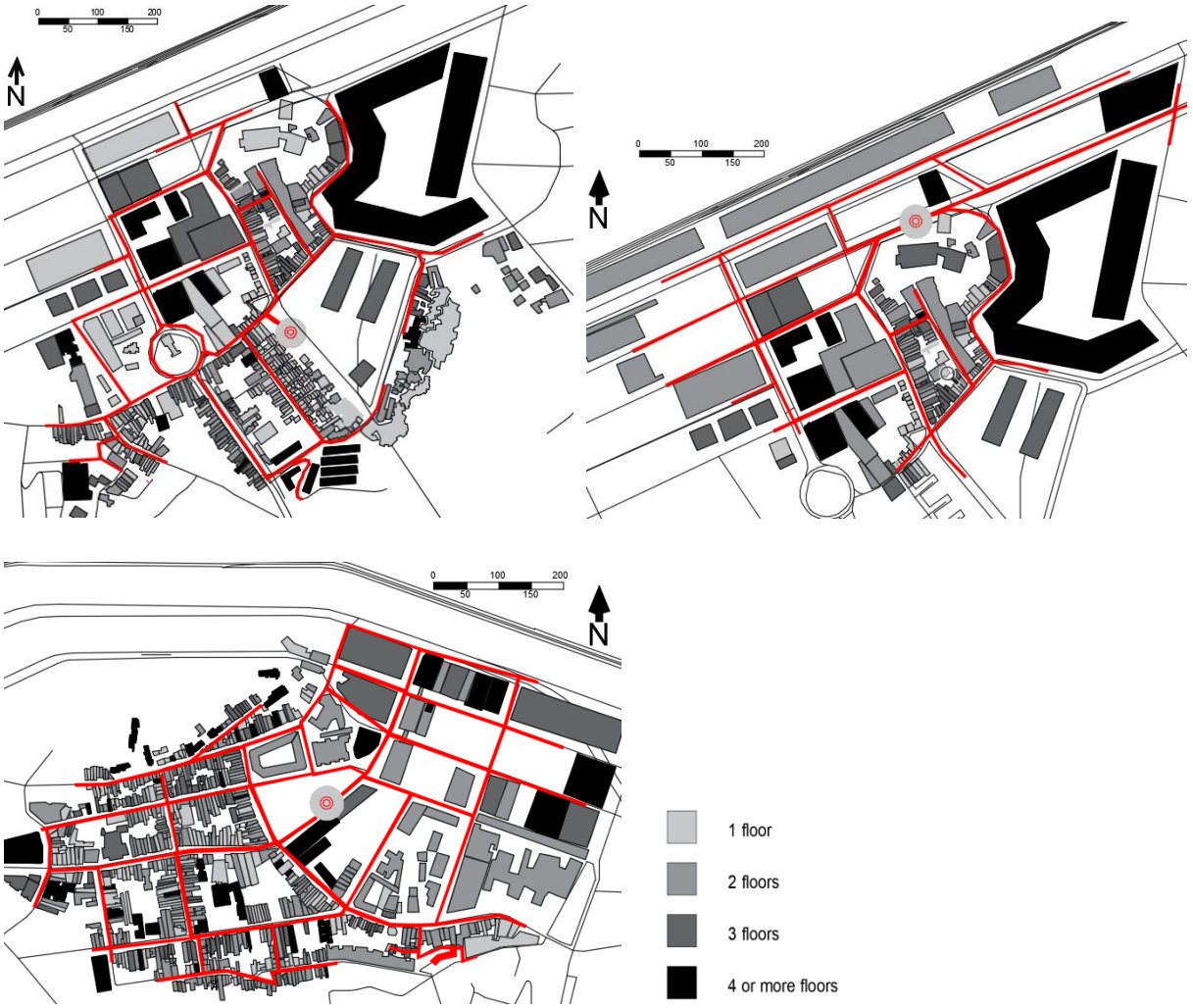


Figure 17 - N. of pavements in Vila Olímpica, Santo Cristo and Harmonia locations by 2010.

4.3.1.1. Population Density

With the square meters and the distinction of the uses in the study areas we obtained the estimated population by 2020 according to the Capacity Index. These numbers are showed in the table below.

Table 10 - Construction area per type of occupation, in the influence area of LRT stations under analysis in 2020.

	Built Area (M^2)	**Residential**		**Non-Residential**				
		Built Area	%	Type 1	Type 2	Type 3	Type 4	%
Vila Olímpica	201 338	44 112	21,91	49 284	76 786	23 101	8 055	78,09
Santo Cristo	165 933	7 335	4,42	34 284	61 161	53 933	9 220	95,58
Harmonia	172 862	35 549	79,44	64 912	30 162	27 866	14 373	79,44

Vila Olímpica. It was possible to observe that the total built up residential area increased, as well as, in non-residential areas - type 1 and type 2, the commercial and institutional constructions showed

additions of built area. In a different way, the quantification of non-residential area - Type 3 industrial warehouses presented a reduction of built area, this change in the amount of constructed area of this typology is also due to the increasing of the non-residential area - type 2 and type 4, headquarters of companies linked to the industrial sector. The reduction of industrial buildings is also the result of the large demolition process of abandoned warehouses.

Santo Cristo. With the square meters and the distinction of the uses in the areas it was possible to obtain the estimated population. It was possible to observe that the total built up residential area has not increased, otherwise, in non-residential areas - Type 1, the commercial and mixed uses constructions showed additions of built area, as well as, the quantification of non-residential area - Type 2 institutional building, and a reduction for the type 3 – industrial warehouses and an addition to type 4, this change in the amount of constructed area of these typologies are also due to the appearance of the non-residential area - type 4 and the reduction of industrial buildings due to the large demolition process of abandoned warehouses.

Harmonia. It was possible to observe that the total built up residential area increased, as well as, in non-residential areas - type 1 commercial use, otherwise the institutional constructions showed a reduction of built area. In a different way, the quantification of non-residential area - Type 3 and 4 industrial uses presented a reduction of built area, this change in the amount of constructed area of this typology is also due to the reduction of industrial buildings and also the result of the large demolition process of abandoned warehouses.

All square meters of residential, non-residential areas and unbuilt area were counted according to the specific occupation characteristics of each typology. Those were considered to get a real picture of the existing population occupation.

Table 11 – Total population per type of occupation, in the period post-implementation.

	Total Population	**Residential**		**Non-Residential**				
		Population	%	Type 1	Type 2	Type 3	Type 4	%
Vila Olímpica	9 705	1 470	15,1	986	6 143	462	644	84,9
Santo Cristo	7 639	245	3,2	686	4 893	1 079	738	96,8
Harmonia	6 603	1 185	17,9	1 298	2 413	557	1 150	82,1

With regard to the type of occupation by number of floors, the table below shows in each location the area occupied by different densities.

Table 12 – Type of occupation by number of floors in the analyzed areas in the post-implementation phase.

Pavements/Floors	Vila Olímpica		Santo Cristo		Harmonia	
	Area (M^2)	%	Area (M^2)	%	Area (M^2)	%
1	66 231	32,22	7 964	5,01	28 248	18,72
2	37 923	18,45	77 220	48,62	69 002	45,72
3	32 877	15,99	8 385	5,28	21 757	14,42
4 or more	68 516	33,33	65 255	41,10	31 924	21,15
Total	205 547	100	158 824	100	150 931	100

Vila Olímpica. The number of floors of buildings in this region continues to clearly demonstrate the low occupancy density characteristic, with approximately 66% of buildings with up to 3 floors and 32% of buildings with only 1 floor. These figures reinforce the characteristics of the historical process of land occupation in this region, where we have the buildings with architectural features of the colonial period and few floors, but the growing increase in irregular residential occupation stands out, especially near the highest region, near the hill.

The buildings with four or more floors are basically contemporary constructions, such as the residential blocks of Providencia and also the built complex of the City of Samba. Still within this group of buildings, with four or more floors, with approximately 33% of the occupation, it is also possible to identify the appearance of some buildings of several floors, in blocks where some abandoned warehouses were demolished, these buildings were already foreseen in the process of revitalization of the port region.

Santo Cristo. The number of floors of the buildings in this region clearly demonstrates the characteristic of low density of occupation, with approximately 60% of the buildings with up to 3 floors, highlighting the buildings with two floors with approximately 48%. These figures reinforce the characteristics of the historical process of land occupation in this region, where we have the buildings with architectural features of the colonial period and few floors.

The buildings with four or more floors are basically contemporary constructions, such as the built complex of the City of Samba and the Olympic Village. Still within this group of buildings with four or more floors, with approximately 41% occupation, it is possible to identify some commercial buildings built after the revitalization of this region and which occupy old demolished warehouses and some multi-family housing buildings.

Harmonia. The number of floors of buildings in this region clearly demonstrates the characteristic of low density of occupation, with 79% of buildings with up to 3 floors, highlighting the two-story buildings with about 45%. These figures reinforce the characteristics of the historical land occupation

process in this region, where we have buildings with architectural features of the colonial period and few floors.

The buildings with four or more floors are basically contemporary buildings, with about 15% occupation, they are commercial buildings, company headquarters and some multi-family housing buildings.

After the changes in land use legislation proposed by the revitalization of the port region, some buildings with larger number of floors were built, but there was a forecast of intense occupation in this area by this type of construction, this forecast was not confirmed.

4.3.1.2. Mix Uses

The table below summarizes the land use occupation in the analyzed areas, in the period after the implementation of the LRT infrastructure.

Table 13 - Land use occupation in the analyzed areas in the post-implementation phase.

Land Use Occupation	Vila Olímpica		Santo Cristo		Harmonia	
	Area (M^2)	%	Area (M^2)	%	Area (M^2)	%
Residential	44 112	21,91	7 335	4,42	35 549	20,56
Commercial	29 536	14,67	25 548	15,40	37 228	21,54
Residential/Commercial	19 748	9,81	8 736	5,26	27 684	16,02
Institutional	76 786	38,14	61 161	36,86	30 162	17,45
Industrial – Warehouse	23 101	11,47	53 933	32,50	27 866	16,12
Industrial – Headquarters	8 055	4,00	9 220	5,56	143 373	8,31
Total	201 338	100	165 933	100	172 862	100

When analyzing the land occupation in **Vila Olímpica** station, it is possible to see that the mix of uses was maintained after the revitalization of the region and also maintained the different characteristics according to its geographical distribution and historical process of urban occupation.

The combined commercial and residential/commercial uses account for approximately 25% of land occupation, however it should be noted that a large proportion of these buildings were already and remain abandoned or in poor condition. A greater combination of uses has continued to be verified, with traditional buildings along the highest flow paths, where 14% commercial and 9,8% residential/commercial uses are found total about 24%.

The high percentage of institutional use stands out, with approximately 38% of urban occupation, due in large part to the dimensions of the City of Samba and Olympic Village buildings.

Industrial use with the warehouses near the port region has been reduced and currently reaches approximately 11% of occupation, while residential use stands out in the upper part, near the hill, where the traditional residential area and irregular residential buildings are located, a process of slumming.

Considering **Santo Cristo** station, the analysis of land occupation showed the predominance of industrial use with the warehouses concentrated on port activities. The different characteristics of urban occupation are in accordance with its geographical distribution and historical process. Industrial use with the warehouses closes to the port region has had a decrease in occupation, due to the demolition of some abandoned warehouses linked to this activity, but still reaches approximately 38% of occupation.

Such reduction can be explained by the increase of commercial areas along the highest flow paths. Summing residential, commercial and residential/commercial uses sum approximately 25%. Combining commercial and residential/commercial uses add up to approximately 20% of the land occupation, with the emergence of commercial efficiencies with many pavements in blocks where the shed was demolished. However, it should be noted that a large part of the buildings is still abandoned or in poor condition.

The high percentage of institutional use presents approximately 37% of urban occupation, given the presence of large-sized buildings as City of Samba, Vila Olímpica and cultural center (former industrial shed).

Analyzing the land occupation in **Harmonia** station, even after the requalification of the port region and the implementation of the LRT transport system, it is possible to identify two different sectors with different occupations, one with predominance of industrial use in large lots, with warehouses concentrated on port activities and another with dispersion of uses in small lots. The different characteristics of urban occupation are in accordance with its geographical distribution and historical process.

Industrial use with warehouses and administrative headquarters of companies has had a large reduction in occupation and is close to the port region reaching approximately 24% of occupation. This reduction is a result of the demolition of abandoned warehouses and also the change of uses, from industrial warehouses to commercial uses and services.

Residential, commercial and residential/commercial uses sum approximately 58% and are concentrated along the highest flow paths. However, it should be noted that a large part of these buildings, mainly commercial and residential/commercial are abandoned or in poor condition. Regarding only residential use, the analysis showed its distribution where an urban occupation of the colonial period is identified, with approximately 20% of land occupation. This concentration is located on roads with small flows.

Institutional use presents approximately 17% of urban occupation, as a result of the presence of military and hospital complexes.

4.4. Reference Point Outside the Influence Area of LRT Stations

In order to understand the direct impact of the LRT deployment in the analyzed stations, in this section we analyze the land use data in the location outside the LRT influence area of the transit infrastructure, giving a picture of the urban changes concerning density and mixed uses in an environmental context not directly affected by the LRT deployment.

Figure 18 - Land use occupation in the reference point pre- (left) and post-(right) implementation.

The following tables present the same method applied in the LRT influence areas, now to obtain the estimated population and land uses in the covered period within the delimited area.

Table 14 - Construction area per type of occupation in the reference point in 2010 and 2020.

	Built Area (M^2)	**Residential**		**Non-Residential**				
		Built Area	%	Type 1	Type 2	Type 3	Type 4	%
2010	12 200	9 587	78,58	1 016	1 567	-	-	21,12
2020	12 706	9 440	74,30	1 242	2 024	-	-	25,70

Table 15 – Total population per type of occupation in the reference point in 2010 and 2020.

Year	Total Population	Residential		Non-Residential				
		Population	%	Type 1	Type 2	Type 3	Type 4	%
2010	466	320	68	21	125	-	-	32
2020	501	315	63	25	162	-	-	37

Table 16 – Land use mix in the reference point in 2010 and 2020.

Land Use Occupation	2010		2020	
	Area (M^2)	**%**	**Area (M^2)**	**%**
Residential	9 587	76,32	9 440	73,14
Commercial	1 161	9,24	1 242	9,62
Residential/Commercial	1 734	13,80	2 024	15,68
Institutional	80	0,64	200	1,55
Industrial – Warehouse	-	-	-	-
Industrial – Headquarters	-	-	-	-
Total	12 562	100	12 906	100

4.4.1. PRE-IMPLEMENTATION

As noticed in the LRT stations, the quantification of the construction areas showed that the total residential area (78%) is much higher than the total non-residential area (21%).

With the distinction of the uses we obtained that the estimated population is also higher in the residential areas, with about 68%, versus 32% in non-residential areas.

32% of population were found in non-residential areas type 1 and 2, from the commercial, residential/commercial and institutional areas identified.

It was identified no industrial occupations. Instead, it was found a number of buildings with broken structure.

4.4.2. POST-IMPLEMENTATION

The results found in the post-implementation have shown that the scenario did not have significative change in the decade under analysis.

Although the total built area has increased, the result revealed a decreased in residential areas (74%) and an increase in non-residential areas (37%) specially type 2 – institutional areas.

Estimated population had also decreased with relation to the previous period, with 63% population in residential and 37% in non-residential areas.

Finally, the land occupation had an overall growth of 2% presenting a symbolic change. Residential areas decreased (from 76% to 73) as a result of an increase of non-residential residential/commercial (from 13% to 15%) and institutional (from 0,6% to 1,5%) uses.

5

DISCUSSION AND MAIN FINDINGS

This section aims to presents the main findings and results concerning the analyzed land use factors in the three LRT stations surroundings under investigation.

5.1. POPULATION DENSITY

Porto Maravilha. The analysis of the evolution on resident population density in the global area of the project has shown that the demographic growth was above the expected during the last decade.

The area comprised by the Neighborhoods of Santo Cristo, Gamboa and Saúde showed very discrete population growth since the implementation of the mega urban revitalization project. While from 2000 to 2010 the population increased 25%, in the current decade the region presented a low increase of about 5%, revealing a deacceleration comparatively to the two decades of analysis.

Although predicting a population increase of the order of 301.610 inhabitants (including the resident, user and floating population) within 15 years from the implementation date, the analysis showed that in two thirds of such time-frame the population growth was very distant from the expected. This reality is due to the most of the proposed projects for the areas - aiming to increase commercial, institutional and residential construction - have not been implemented.

LRT Stations. Regarding the LRT stations, the quantification of the constructed areas of building types obtained by mapping our research areas has shown that despite the increase in population within the residential areas, no significant increase has been observed for the analyzed time period. However, some important considerations include:

- The total number of people had an increase (although low) of about 33% in Vila Olímpica, 35% in Santo Cristo, and 21% in Harmonia.

- Population in residential area remains the same, but non-residential areas showed the highest increases in buildings of type 4 (Vila Olímpica and Santo Cristo), as well as in type 1 (Santo Cristo bigger than Vila Olímpica)

Vila Olímpica. The non-residential commercial and mixed uses areas (type 1), there was no significant increase of the population. The increase found in Santo Cristo (144%), can be also explained by the lower density found in the period before the implementation of the LRT.

Despite the size of the existing buildings, the analysis on the population in non-residential institutional use (Type 2) showed also no significant increase in the population during this period of time.

The reduction found in non-residential areas Type 3 is understood as a result of the demolition process of abandoned or underused buildings to allow the construction of new buildings.

The emergence of a new type of building, non-residential Type 4, was already foreseen in the process of revitalization of the Port and with the implementation of a new transport modal – LRT system, with a large offer of areas available for construction and with the necessary infrastructure. Despite the emergence of this typology, the total built area and consequent population derived from this typology was much lower than initially predicted.

The following graphics present the population variation in Vila Olímpica, Santo Cristo and Harmonia LRT stations occurred during the current decade in a comparative way.

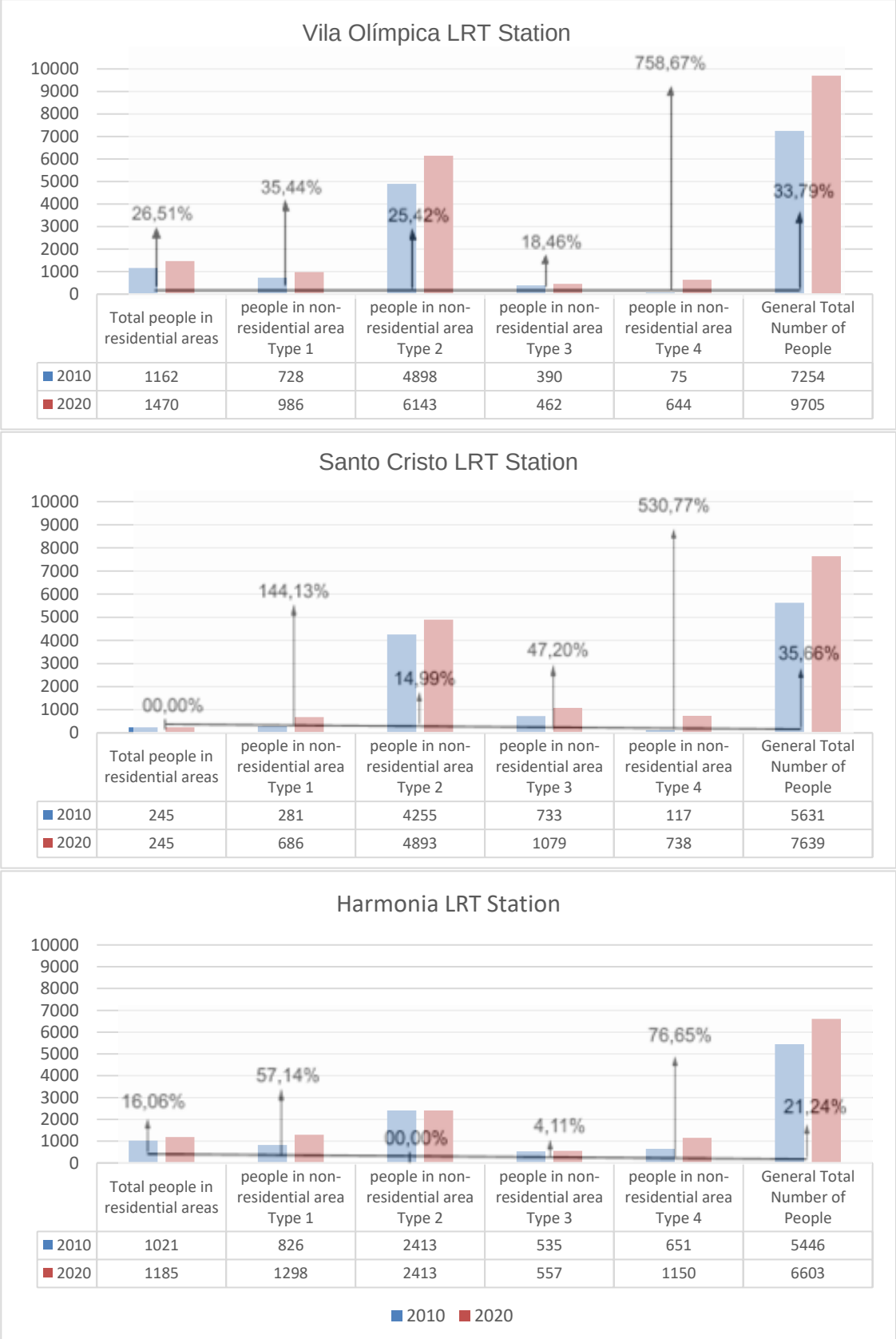


Figure 19 - Population variation in Vila Olímpica, Santo Cristo and Harmonia LRT stations.

5.2. LAND USE MIX

Porto Maravilha. As a result of the non-implementation of great part of the projects expected in the overall Porto Maravilha region, the main transformations in land uses was the reconversion of areas before characterised by industrial uses and abandoned constructions into commercial and mixed (residential/commercial) areas, as well as the implementation of sporting and cultural institutional buildings aimed to respond the mega sporting-event occurred in 2014 and 2016.

Such results support the analysis in the **LRT stations**. Comparing the numbers in each study area in percentual of change (showed in the table below), some points are highlighted with respect to the three locations:

- A general increase in area destinated to commercial use and (although very discrete) in residential areas;

- A general decrease in areas destinated to industrial activities, mostly warehouse's type.

Table 17 - Land use occupation (in percentage %) in pre- and post-implementation phases.

Land Use Occupation	Vila Olímpica		Santo Cristo		Harmonia	
	2010	**2020**	**2010**	**2020**	**2010**	**2020**
Residential	19,60	21,91	4,61	4,42	17,06	20,56
Commercial	9,37	14,67	3,34	15,40	7,57	21,54
Residential/Commercial	11,10	9,81	5,48	5,26	15,41	16,02
Institutional	34,41	38,14	33,39	36,86	16,79	17,45
Industrial – Warehouse	24,35	11,47	51,14	32,50	33,10	16,12
Industrial – Headquarters	1,17	4,00	2,04	5,56	10,07	8,31

Vila Olímpica. Despite the revitalization of the Port region and the implementation of the LRT, discrete changes in land occupation were observed in Vila Olímpica station, during the analyzed time period. Residential and commercial uses increased, while residential/commercial and industrial uses decreased.

Residential use showed small increase, from 19% to approximately 22%; commercial use as well, from 9% to about 14%. Institutional use was already high 34%, going to approximately 38% since the revitalization project.

For residential/commercial the analysis showed the changes proposed by the revitalization project result in a decrease to about 9% of this land use occupation which was already low (11%) before the implementation. For industrial use, with the combination of warehouses and headquarters of companies,

it was identified a decrease from approximately 25% to about 15% as a result of the reduction of galleries and increase of head offices in the region.

Santo Cristo. With also discrete changes, in Santo Cristo the results showed that residential and residential/commercial uses remained the same remained low 4.4% even with the changes propose by the revitalization.

The analysis has shown increases in commercial, institutional and headquarters industrial uses, while presented a decrease in warehouses' industrial use. Commercial use reached 15%, institutional 37% and industrial of about 5%, numbers that before the implementation were 3%, 33% and 2% approximately.

Harmonia. The location of Harmonia station has shown increase in residential and commercial use, while decreases in industrial uses. Residential/commercial and institutional occupation have presented no significative changes.

Residential use increased from 17% to approximately 20,5%; commercial use has increased from 7,5% to 21,5% with the changes proposed by the project.

For industrial use, with the combination of warehouse and headquarters of companies, it was identified that its representativity was already high and with approximately 43% and with the changes proposed by the revitalization, it was obtained a reduction of its representativity, reaching approximately 24%. The percentage reduction in galleries and the percentage increase in headquarters should be highlighted.

To summarize, the profile of land occupation in the location of Vila Olímpica and Harmonia revealed diversity of uses and density of occupation. In the location of Santo Cristo has shown significant emphasis on institutional and industrial uses.

The implementation of the LRT System and the Revitalization of the Port Region had little influence on land occupation but showed greater occupation of abandoned industrial buildings and creating new uses for these buildings, as well as with emphasis on commercial and institutional uses.

Harmonia had the highest percentage of residential, commercial and mixed occupancy. The implementation of the LRT and the revitalization of this area reinforced these characteristics of occupation with emphasis on commercial use, resulting from the construction of new commercial buildings.

Figure 20 – Comparative graph of land use occupation in pre- and post-implementation phases.

Table 18 – Number of floors (in percentage %) in pre- and post-implementation phase.

Pavements/Floors	Vila Olímpica		Santo Cristo		Harmonia	
	2010	2020	2010	2020	2010	2020
1	35,64	32,22	6,05	5,01	15,74	18,72
2	17,35	18,45	58,55	48,62	45,82	45,72
3	13,89	15,99	1,28	5,28	22,90	14,42
4 or more	33,12	33,33	34,13	41,10	15,54	21,15

With regard to the number of floors, the analysis revealed the greater changes in Santo Cristo and Harmonia stations. Vila Olímpica, although presents at least 49% of building with more than 3 pavements (from which 33% with 4 or more), has showed no significant change since the implementation of LRT.

The best verticalization (built density) was found in Santo Cristo, with up to 40% of the land use occupation with buildings with 4 or more floors, percentual of which before the implementation were 34%. This location also showed increase in 3-floor buildings, while decrease in 1 and 2-floor buildings.

Finally, although showed lower number of 4-or-more-floors buildings, Harmonia station also revealed variations in the verticalization of its region during the last decade.

Figure 21 – Comparative graph of number of floors in pre- and post-implementation phases.

Reference Location. The analysis using a reference location outside the LRT influence area has brought an image of the analyzed indicators without the influence of the new transit infrastructure for effects of comparison.

The results found have shown that the scenario did not have significative change since the deployment of the revitalization project and LRT implementation. However, contrary to the LRT station's scenario, the analysis has shown that the estimated population in the reference point revealed to be higher in the residential areas, than in non-residential areas. Estimated population in residential areas has decreased with relation to the previous period, with 63% population in residential and 37% in non-residential areas, as a result of an increase of non-residential residential/commercial (from 13% to 15%) and institutional (from 0,6% to 1,5%) uses.

These results express a great difference in the land use occupation in this location in relation to the LRT surroundings. The land use occupation found as non-residential area is the type 1 and 2, while no

industrial occupation is found. Although revealed no industrial occupations, it was still found a number of buildings with broken structure.

5.3. LRT USER VS. POPULATION

Combining the data from population and users profile collected from IBGE and the mobility LRT survey (2017), it was possible to analyze whether the resident population in Santo Cristo, Gamboa and Harmonia is a potential user of the transit modal.

The graphs below present the socio-economic characteristics according to gender, age-group, educational level, social and economic situations of individuals living closely the transit stations and those indeed using the LRT system.

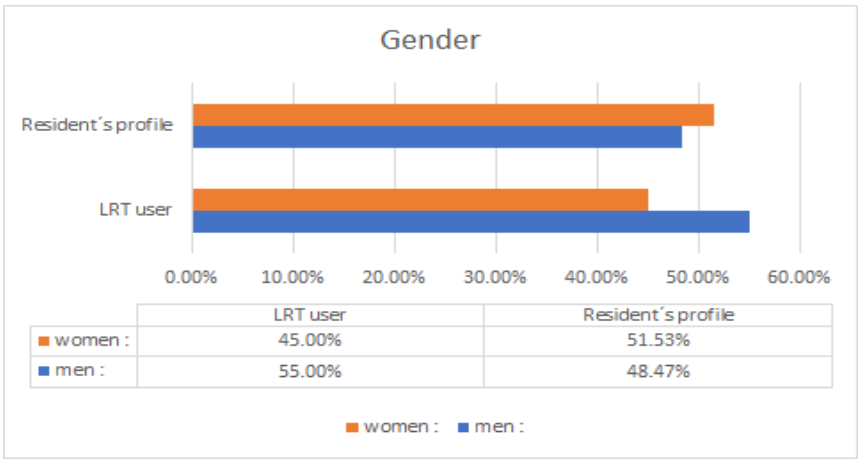
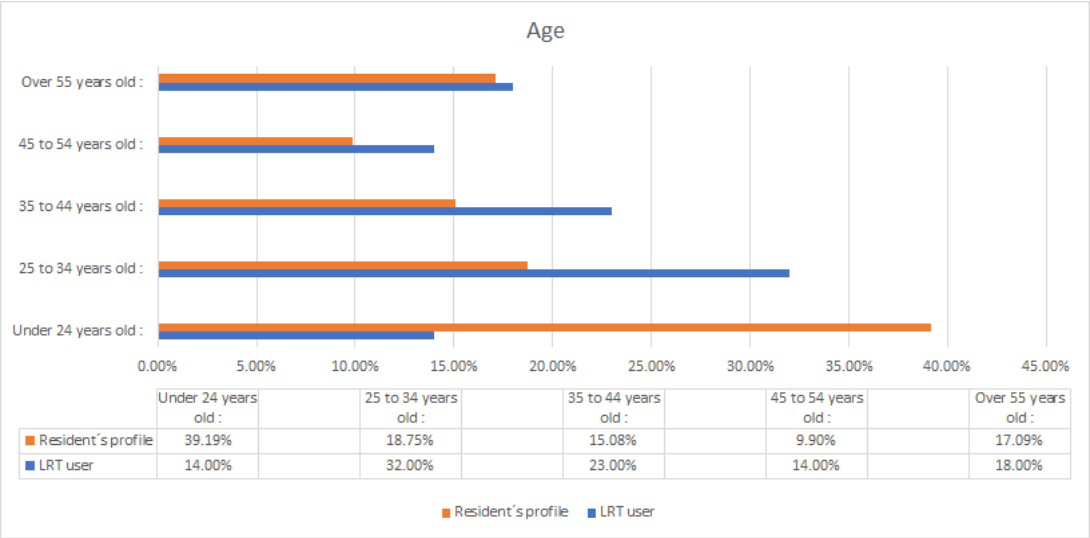


Figure 22 - Gender and Age-groups of population and LRT users.

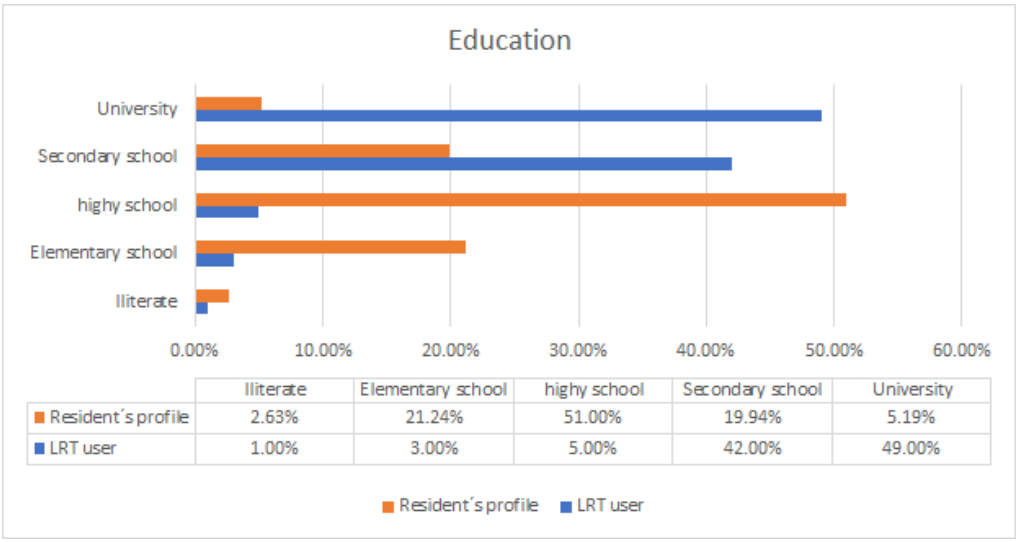
While the gender groups of the residents revealed similar between the analyzed groups, there is a big difference between the age-groups. Resident profile mot expressive showed to be young-adult under 24 years-old. Among the LRT users, groups of 25-34 years-old was found as the most expressive (32%) followed by 35-44 group (23%) and over-55 (18%).



	Under 24 years old :	25 to 34 years old :	35 to 44 years old :	45 to 54 years old :	Over 55 years old :
Resident´s profile	39.19%	18.75%	15.08%	9.90%	17.09%
LRT user	14.00%	32.00%	23.00%	14.00%	18.00%

Figure 23 - Gender and Age-groups of population and LRT users.

Regarding the educational level, while the most common user profiles showed to have secondary and high education levels, the majority of population living in the overall region has finished the high school.



	Iliterate	Elementary school	highy school	Secondary school	University
Resident´s profile	2.63%	21.24%	51.00%	19.94%	5.19%
LRT user	1.00%	3.00%	5.00%	42.00%	49.00%

Figure 24 - Educational level of population and LRT users - Gamboa, Santo Cristo, Saúde.

The most significative differences were found with respect to the social class and average income between the analyzed groups, revealing antagonist profiles among the two groups, as shown the following graphs. The most common user profile represent population belonging to the Class B and C, while Class D/E presents very discrete weight. This huge disparity reveals that although covered by the transit infrastructure, the vulnerable groups living in the overall area of Porto Maravilha has no access to the LRT service – due the high rates of unemployment or other exclusion factors.

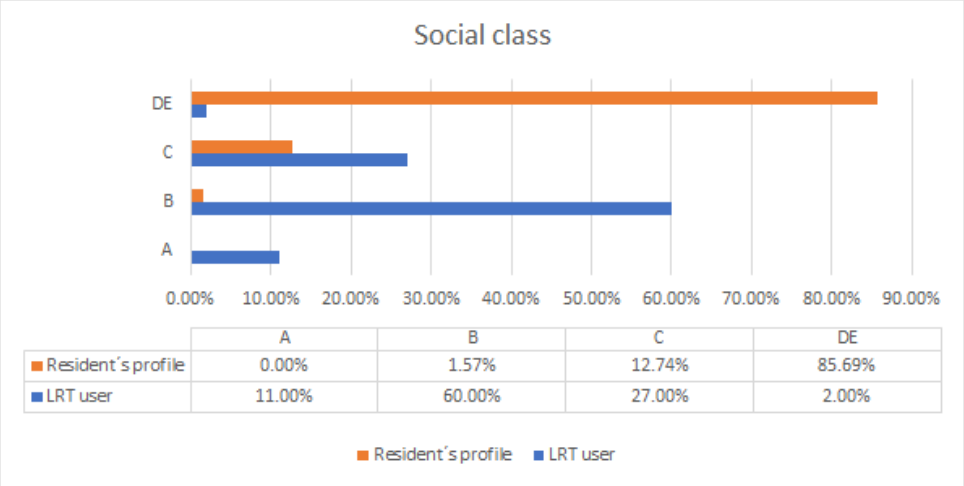


Figure 25 – Social Situation of residents and LRT users.

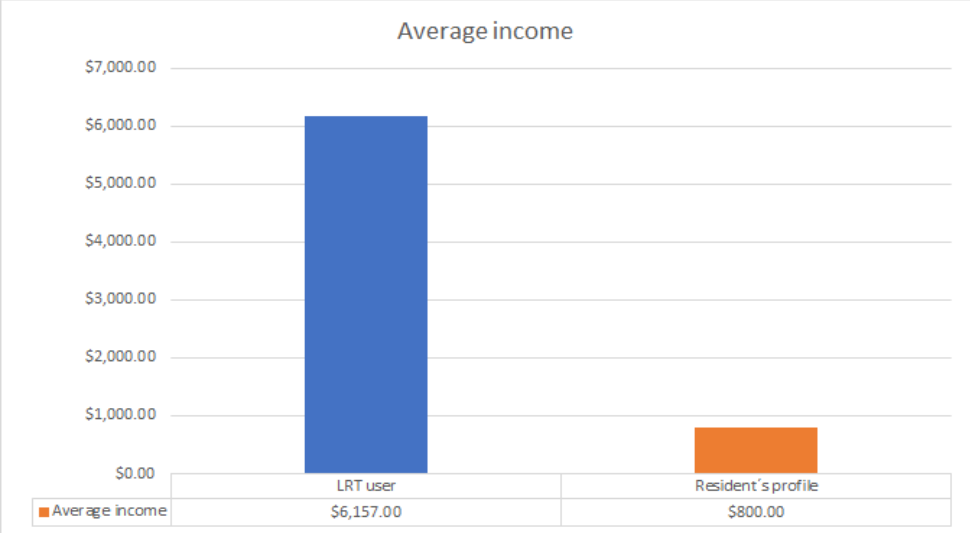


Figure 26 - Educational level, social and economic situations.

Finally, with regard to the economic situation, the graph above reveals big differences among the two groups, reinforcing the previous results.

These findings support the assumption that the new LRT infrastructure does not cover the population living in the LRT surroundings, although its proximity. In fact, massive investment was made in order to revitalize the region bringing also several land use “expectations” of densification and verticalization to the Porto Maravilha region.

6
CONCLUSION

This study aimed to investigate the changes in land use impacts in the immediate surroundings of the LRT stations of Vila Olímpica, Santo Cristo and Harmonia occurred during the last decade as a result of the implementation of Porto Maravilha regeneration project.

In the overall area of Porto Maravilha, the population growth one decade after the implementation of the project revealed way below of the expected.

While the Port region showed a population increase of about 5%, the LRT surroundings under investigation had a better increase - of about 33% in Vila Olímpica, 35% in Santo Cristo, and 21% in Harmonia - suggesting that the deployment of the LRT network is somehow contributing to the population increase.

Although the most of the proposed projects aiming to increase commercial, institutional and residential construction have not been implemented, the analysis also revealed changes (yet low) in the type of occupation in the influence area of LRT stations covered in this study. The results showed increase in commercial and mix (residential/commercial) uses while a decrease in industrial uses, especially warehouse types. With more commercial and general services, such locations beneficed by an increase in job opportunities during the last decade.

Given the socio-demographic characteristics of the resident population does not coincides with the LRT users' profile, we can assume that such a transit mode contributes rather to the accessibility of population at the regional level (City of Rio de Janeiro), than to the local accessibility of population living in the stations' surroundings. Thus, although the region concenters high number of job opportunities allowed by the new occupations and transport infrastructure, does not yet housing the work force.

It is important to mention yet that other factors might have contributed to the discrete changes in population density and land uses in the study areas and the port region, such as in socio-economic and political sphere, bringing an insufficient stability-image of Brazil face national and international

markets. As a result, great part of the investments and capital required to the success of the great urban revitalization project of Porto Maravilha did not happened as expected. Such fragile scenario reinforces what has been said in previous works about the limitations of the urban entrepreneurship in the contemporary urban planning.

Further research contributions

Further research is needed to support the contributions added with this study, analyzing other factors impacted by the deployment of the LRT system in Rio de Janeiro, as well as covering the other stations surroundings.

Another suggestion includes the application of this research methodology using the next census data available by the end of 2021. Updated data can reveal an accurate picture of the land use changes occurred in the current decade, since the deployment of the revitalization project and the LRT network.

6
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