UNIVERSIDAD
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FACULTAD DE INGENIERIA

# Towards sustainable mobility

## New solutions and approaches for Sustainable Urban Mobility Plans

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Programa de Posgrado
Maestría en Gestión de la Innovación
Facultad de Ingeniería
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# ABSTRACT

Sustainable mobility is a very relevant approach within the novel paradigm of smart cities. Modern urban areas have been built around automobiles, limiting pedestrian zones and reducing the circulation space for others sustainable transportation modes . Mobility have resulted in growing levels of motorization and congestion, causing many environmental problems, accidents on roads and lack of accessibility. The need of moving towards sustainable mobility is one of the Sustainable Development Goals (SDGs), adopted by the United Nations in 2015 as a universal call to action to end poverty, protect the planet, and ensure that by 2030 people will have a better quality of lives.

This thesis proposes studying and analyzing good practices, measures, and urban planning approaches of sustainable development successfully applied in other countries, which can help as good examples to be applied in Montevideo. Also, the thesis proposes designing sustainable mobility plans to limit the use of private vehicles by improving public transportation, encouraging sustainable transportation modes, creating pedestrian zones, and changing the negative transformation caused by automobile dominance. The main contributions of this thesis are: reviewing the most relevant works related to sustainable mobility around the world and in our country; analyzing and characterizing sustainable initiatives of public transportation in Montevideo; demonstrating the viability of implementing a sustainable mobility plan in an specific area of Montevideo considering subjective opinions of people traveling from/to the area; and evaluating the same specific area of Montevideo using Transit Oriented Development, a well-known planning approach for sustainable development.

The applied methodologies include urban data analysis (using operational data, personal inspection and a survey), mobility indicators and Transit Oriented Develpment (TOD) metrics. The main results of the study are that the coverage area of the sustainable mobility initiatives is a small fraction of the total area of the city, thus a significant part of the population of Montevideo cannot access to sustainable transportation modes; regarding Parque Rodó and Engineering Faculty, most of the people travel from/to near locations (less than 5 kms); land use in the studied area is diverse and it shows a reasonable compactness and good degree of functional mix which suggests that the impact of implementing a sustainable mobility plan in the area will have notable results.

Overall, this thesis contributes as a tools for helping academics, transportation companies, and stakeholders to analyze and evaluate possible solutions to implement sustainable mobility plans. The mobility analysis of Parque Rodo neigborhood as TOD approach is the first academic work developed for a specific area in Montevideo. Regarding the replicability of the study, the proposed methodologies can be applied to characterize the mobility demands and the sustainable mobility analysis on other relevant neighborhoods in the city. In addition, the reported case of study in Parque Rodó neighborhood provides a basis for building more powerful surveys and data collection activities to better understand sustainable mobility in the whole city.

Keyword:
Sustainable mobility, Smart cities, Sustainable urban mobility plan, Transit oriented development, Urban public transportation system, Sustainable development, Technology, Innovation..

# Contents


**1 Introduction** **1**

**2 Methodology** **4**

2.1 General description and objectives . . . . . 4

2.1.1 Main questions that guide this thesis . . . . . 4

2.1.2 General objective and specific objectives . . . . . 5

2.1.3 Main results of the thesis . . . . . 5

2.2 Collaborations and data sources . . . . . 6

2.3 Methodology for characterizing the mobility demand in the surrounding area of Engineering Faculty . . . . . 7

**3 Activities and risks** **10**

3.1 Work plan . . . . . 10

3.1.1 Activity 1: analysis of the state of the art . . . . . 10

3.1.2 Activity 2: Sustainable mobility initiatives in Uruguay . 11

3.1.3 Activity 3: Sustainable Public Transportation Initiatives in Montevideo . . . . . 11

3.1.4 Activity 4: Study of the mobility demands on a specific zone of Montevideo . . . . . 12

3.1.5 Activity 5: Integration of electric mobility in the sustainable mobility plan for a specific area of Montevideo . 12

3.1.6 Activity 6: improvement of urban planning in the city . 13

3.2 Risk assessment and contingency plans . . . . . 13

3.2.1 Activity 1 - Risk 1 . . . . . 13

3.2.2 Activity 2 - Risk 1 . . . . . 14

3.2.3 Activity 3 - Risk 1 . . . . . 14

3.2.4 Activity 4 - Risk 1 . . . . . 14

3.2.5 Activity 5 - Risk 1 . . . . . 15

4 **Related work** **17**

4.1 Sustainable mobility . . . 17

4.2 Transit Oriented Development . . . 21

4.3 Sustainable mobility initiatives in Uruguay . . . 24

4.3.1 Urban mobility plan of Montevideo . . . 24

4.3.2 MOVES project . . . 26

4.3.3 On-demand mobility initiatives . . . 28

4.3.4 Electric mobility initiatives . . . 31

4.3.5 Promotion of walking and discourage the use of private motorized vehicles . . . 32

4.3.6 Public transportation system and universal and sustainable accessibility . . . 34

4.4 Summary . . . 35

5 **Sustainable mobility in the public transportation of Montevideo, Uruguay** **41**

5.1 Introduction . . . 41

5.2 Sustainable mobility . . . 43

5.3 Sustainable public transportation initiatives in Montevideo . . . 45

5.3.1 The public transportation system of Montevideo, Uruguay 45

5.3.2 Sustainable mobility initiatives in Montevideo . . . 46

5.4 Analysis of sustainable mobility in Montevideo . . . 46

5.4.1 Indicators to assess sustainable mobility . . . 47

5.4.2 Results of the analysis . . . 50

5.4.3 Qualitative Indicators . . . 55

5.4.4 General recommendations for sustainable mobility initiatives in Montevideo . . . 57

5.5 Summary . . . 59

6 **Sustainable mobility plan for Engineering Faculty and Parque Rodó neighborhood, Montevideo** **61**

6.1 Introduction . . . 62

6.2 Mobility analysis and survey . . . 64

6.2.1 Engineering Faculty and Parque Rodó neighborhood . . 64

6.2.2 Motivation and objectives of the study . . . 65

6.2.3 Methodology for collecting data . . . 66

6.2.4 Methodology for data analysis . . . . . . . . . . . . . . . 68
6.3 Analysis of results . . . . . . . . . . . . . . . . . . . . . . . . 69
6.4 General recommendations for sustainable mobility initiatives in Parque Rodó neighborhood and Engineering Faculty . . . . . . 77
6.5 Summary . . . . . . . . . . . . . . . . . . . . . . . . . . . 80

**7 A practical approach for sustainable Transit Oriented Development in Montevideo, Uruguay 82**
7.1 Introduction . . . . . . . . . . . . . . . . . . . . . . . . . . 83
7.2 TOD approach . . . . . . . . . . . . . . . . . . . . . . . . . 85
7.3 TOD-based sustainable mobility analysis for Engineering Faculty, Montevideo, Uruguay . . . . . . . . . . . . . . . . . . . . 87
7.3.1 Motivation and objectives of the study . . . . . . . . . . 87
7.3.2 Methodology . . . . . . . . . . . . . . . . . . . . . . . 87
7.4 TOD-based sustainable mobility analysis for Parque Rodó neighborhood, Montevideo, Uruguay . . . . . . . . . . . . . . . 91
7.4.1 Land use . . . . . . . . . . . . . . . . . . . . . . . . . 92
7.4.2 Density . . . . . . . . . . . . . . . . . . . . . . . . . . 93
7.4.3 Compactness and mix . . . . . . . . . . . . . . . . . . 94
7.4.4 Public spaces . . . . . . . . . . . . . . . . . . . . . . . 96
7.4.5 Transit/public transportation . . . . . . . . . . . . . . . 97
7.4.6 Connectivity, ciclying, and walkability . . . . . . . . . . 97
7.4.7 Mobility demand and shift to sustainable transportation modes . . . . . . . . . . . . . . . . . . . . . . . . . 101
7.5 Suggestions and recommendations to improve sustainable mobility under the TOD paradigm . . . . . . . . . . . . . . . . . . 104
7.6 Summary . . . . . . . . . . . . . . . . . . . . . . . . . . . 106

**8 Conclusions 108**

**Bibliography 111**

# Chapter 1

# Introduction

Smart cities have become one of the most interesting research topics, in response to the rapid urbanization, digital revolution, and the high demand of societies asking for a more efficient and sustainable urban services and a better quality of life (Goi, 2017). Several interpretations regarding smart city were introduced since this term appeared. The more comprehensive way of understanding a smart city is by combining the main concepts of intelligent city and sustainable city. The convergence of both concepts creates cities more inclusive, secure, sustainable and based on information technologies (Guedes et al., 2018). Technology innovation help cities operate more efficiently, improving services to citizens whereas sustainability improves the quality of life taking care of the environment. Moreover, the evolution of smart cities can manage resources intelligently to become economically, socially, and ecologically convenient.

Urban mobility plays an important role in the ecosystems of smart cities. Mobility is defined as "the ability to travel from one place to another using one or more modes of transportation, to meet daily needs" (Eltis, 2019). A major factor in smart cities are the new technologies used for urban mobility, which are usually aimed at improving sustainability. The transition to low-carbon and circular economy are some of the essential aspects to improve in urban mobility, aligned with concepts of sustainability (Zawieska and Pieriegud, 2018).

Modern urban areas have been built around automobiles. Streets have been widened in many cities to accommodate automobiles, limiting pedestrian zones and reducing the circulation space for others sustainable transportation modes. Private vehicles have revolutionized mobility. However, the increase in the use of private vehicles has raised the number of accidents on the roads; pollution, environmental degradation, congestion, a decline in public transportation, lack of accessibility, etc. As a consequence, many cities around the world are designing sustainable mobility plans to limit the use of private vehicles by improving public transportation, encouraging sustainable transportation modes, creating pedestrian zones, and changing the negative transformation caused by automobile dominance.

While acknowledging the importance of private car mobility in modern cities, this thesis focuses on analyzing sustainable transportation initiatives as an important mean of promoting the shift from automobile to more sustainable transportation modes. In addition, the thesis proposes analyzing a specific zone of Montevideo to evaluate the viability of introducing a sustainable mobility plan. In this line of work, the main motivation of the thesis is to analyze and characterize the current reality regarding sustainable public transportation in Montevideo in order to make mobility more sustainable and analyze how the studied area can be transformed in a walkable, compact, pedestrian-oriented, and mixed-use community, where people want to live and work, built around sustainable public transportation.

The main contributions of this thesis are: reviewing the most relevant works related to sustainable mobility around the world and in our country; analyzing and characterizing sustainable initiatives of public transportation in Montevideo; demonstrating the viability of implementing a sustainable mobility plan in an specific area of Montevideo considering subjective opinions of people traveling from/to the area; and finally, evaluating the same specific area of Montevideo using Transit Oriented Development(TOD), a well-known planning approach for sustainable development. This thesis proposes studying and analyzing good practices, measures, and urban planning approaches of sustainable development successfully applied in other countries, which can help as good examples to be applied in Montevideo. In addition, the thesis propose gathering mobility information from open data sources and from urban data analysis in Uruguay. Several mobility indicators are proposed and developed to study and analyze sustainable mobility in Montevideo. Finally, several suggestions and recommendation are propose in the study to improve urban transportation, regarding sustainable mobility and TOD.

The developed research was reported in the article ‘Sustainable Mobility in the Public Transportation of Montevideo, Uruguay’, Smart Cities, ICSC-CITIES 2019, Second Ibero-American Congress, Revised Selected Papers, Series Communications in Computer and Information Science, Springer (Hipogrosso and Nesmachnow, 2020b) and later expanded in the journal publication ‘Analysis of Sustainable Public Transportation and Mobility Recommendations for Montevideo and Parque Rodó Neighborhood’, Smart Cities, 3(2), 479-510, 2020 (Hipogrosso and Nesmachnow, 2020a). Finally, the analysis applying TOD in the article ‘A practical approach for sustainable Transit Oriented Development in Montevideo, Uruguay’ published in Smart Cities, ICSC-CITIES 2021, IV Ibero-American Congress, Revised Selected Papers, Series Communications in Computer and Information Science 1555, Springer (Hipogrosso and Nesmachnow, 2021).

The thesis is organized as follows. Chapter 2 describes the methodology proposed for the analysis and the main data source used to achieved the objectives. Chapter 4 presents the review of the main related works of sustainable mobility and transport oriented development developed. Chapter 5 presents the analysis of sustainable mobility initiatives recently developed in the public transportation of Montevideo, Uruguay. Chapter 6 presents a practical approach for analysis and implementation of a sustainable mobility plan in Parque Rodó neighborhood, Montevideo. Chapter 7 presents an empirical analysis of sustainable mobility under the Transit Oriented Development paradigm. Finally, Chapter 8 presents the main conclusions of this thesis and suggests some ideas for future work.

# Chapter 2

# Methodology

This chapter presents the methodologies that guide this research and describes the main data sources used to achieve the objectives.

## 2.1 General description and objectives

This thesis proposes analyzing the main related work and good practices of sustainable urban mobility developed in cities around the world where its well-known success serves as a reference to improve mobility in the city of Montevideo. The main research questions, objectives, and expected results are described in this section.

### 2.1.1 Main questions that guide this thesis

The main questions that guide this research are:

- How sustainable mobility has evolved in Montevideo?
- What sustainable mobility initiatives have been recently developed in Montevideo?
- How technology could reduce carbon emissions?
- What mobility measures are effective to reduce the use of cars?
- What sustainable transportation modes are developed in Montevideo and how accessible are them?
- What changes can be done in the urban infrastructure to reduce car use and promote sustainable mobility in Montevideo?
- What is the relationship between mobility and accessibility?

- How the new mobility services that appeared in the last few years (electric scooter, carsharing, etc) have impacted in urban mobility?

### 2.1.2 General objective and specific objectives

The main objective of this thesis is to contribute to the improvement of urban transportation system of Montevideo with sustainable mobility measures.

The specific objectives of the thesis include:

- Study and analyze the main related work of sustainable mobility and transport oriented development developed in the world and Uruguay.
- Characterize the different sustainable mobility initiatives that are operating in Montevideo through public or private transportation companies.
- Characterize the accessibility in the urban public transportation system of Montevideo.
- Characterize the type of citizens, their trips and their main mobility motivations.
- Integrate electric mobility to the sustainable mobility plans as an alternative fuel of Co2.
- Improve urban planning and reorganize urban transportation system to achieve more effective mobility.
- Improve public spaces by promoting walking and the use of sustainable transportation.
- Analyze good practices and measures that could be viable from an economic, social and environmental point of view in Montevideo.

The specific objectives are related to the activities proposed in the work plan, which is presented in Section 3.1.

### 2.1.3 Main results of the thesis

The review of the most relevant works related to sustainable mobility was useful to find good practices and measures applied in other cities that serves as examples to be replicated in the city of Montevideo. In addition, the analysis and characterization of the sustainable initiatives of public transportation in Montevideo are a valuable tools for helping academics, transportation companies, and stakeholders to analyze and evaluate possible solutions to implement sustainable mobility plans. In particular, the case study of Parque Rodó neighborhood demonstrates the viability of implementing a sustainable mobility plan in specific area of Montevideo and provides a basis for building more powerful surveys and data collection activities to better understand sustainable mobility in the whole city. It is important to highlight that the implementation of a sustainable mobility plan in a specific area must combine the analysis of the mobility demand of people traveling from/to the area and the analysis of the urban environment and both need to be developed at the same time.

## 2.2 Collaborations and data sources

This thesis required the collaboration of institutions, professors and researchers expert on the field of urban transportation and sustainability.

This thesis proposes analyzing the different mobility options available in the city of Montevideo, to determine the viability and the scope of the most sustainable and accessible solutions for citizens, including clean vehicles, low-emission vehicles and other options. To achieve this objective, the study proposed working in cooperation with project MOVES of the Ministry of Industry, Energy and Mining (MIEM) (MIEM, 2017). Project MOVES aims to promote an effective transition to inclusive, efficient and low-carbon urban mobility in Montevideo by evaluating clean technologies. Furthermore, MOVES proposed promoting a cultural change towards sustainable transportation modes. Both lines of work provide useful information for the research, such as excessive use of energy, environmental pollution, road traffic, congestion, etc. Also, the study received operation information of the pilot plan of CUTCSA using an electric bus in public transportation. CUTCSA, as one of the main public transportation companies operating in Montevideo, has shown their interest for moving towards cleaner energies in order to reduce its carbon footprint. A pilot plan is in course since 2017, using one electric bus that operates in different lines to test the performance of this new transportation mode. The pilot plan using electric bus has been considered an important advance for public transportation system of Montevideo.

The thesis also proposed using open data source and data obtain from different institutions interested in this proposal. Open data sources are available in Open Data Catalog from the national government and in the Geographical Information System from the City Hall of Montevideo (IM), which include data related to road infrastructure (streets and bicycle lanes), data from public transport system (bus lines, bus stops and bus schedules), data from different points of interest in the city (parking facilities, tourist attractions, etc.), socio-economic data collected by the INE (National Statistics Institute). The other data sources used correspond to the information of location and sale tickets of the Metropolitan Transportation System (STM) and GPS information from buses, obtained in the public web services of IM and transportation companies. The thesis also extracted data of urban infrastructure to characterize universal accessibility. Finally, the study used data provided by the National Directorate for Territorial Management (DINOT), contained in the Territorial Information System and the Territorial Management Inventory, as well as other data provided by the DINOT Mobility Working Group.

## 2.3 Methodology for characterizing the mobility demand in the surrounding area of Engineering Faculty

The thesis applies a mixed approach, considering quantitative and qualitative indicators, which is the dominant methodology for sustainable mobility analysis, according to the review by Anagnostopoulou et al. (2018). Furthermore, for the case study of Parque Rodo neighborhood a survey based on specific interviews to a sample of people moving to/from the studied area was performed. Resulting data were analyzed both using quantitative and qualitative indicators. Finally, the study of a specific area was analyzed using TOD approach, a planning and design strategy that has helped many cities reduce their carbon footprint. The considered indicators are defined in Section 5.4.1; the performed survey is described in Section 6.2.3; and the computed TOD metrics and indicators are reported in Section 7.3.2.3.

For analyzing the sustainable mobility in the public transportation of Montevideo, the thesis considers sustainable mobility indicators proposed by World Business Council for Sustainable Development (2015). Qualitative and quantitative indicators are useful tools for cities to evaluate the current situation of the mobility system, and to evaluate the potential impact of selected solutions. Each indicator represents an aspect of mobility and is often interconnected with other mobility indicators. For instance, intermodal connectivity and intermodal integration are closely linked and so are comfort and pleasure and travel time. Holistically optimized solutions are obtained when considering the interconnections: solutions might improve several related indicators in parallel. All indicators are calculated as this enable an holistic understanding of the current mobility situation and allow to outline mobility plans. Results of the analysis to characterizes sustainable mobility initiatives are reported in Section 5.4.2.

For the case study of Parque Rodó neighborhood, the methodology applied for collecting data used in-situ interviews in the studied area selected random. The purpose of the survey is to explore the main motivations of individuals that travel to/from the studied area, the mean of transportation they use to travel, and their willingness to change to a more sustainable mean of transportation. Interviews are qualitative methods that are believed to provide a 'deeper' understanding of the study than would be obtained from questionnaires and are more appropriate where not enough information about the studied phenomenon (in this case, the mobility demand of the studied area) is available.

In order to create a suitable sustainable mobility plan for the area of Parque Rodó neighborhood, the survey considers a proper sample size of the universe of study. In comparison with the mobility survey of Montevideo (Mauttone and Hernández, 2017), the study of Parque Rodó neighborhood interviewed the same number of people to analyze an area 400 time smaller than Montevideo. In addition, the interviews to collect the data were performed in-situ, face to face, at different hours of the days, to different types of citizens, and in different places of the studied area, whereas the methodology used for collecting data in the Mobility survey of Montevideo consisted in households surveys, face to face, to a group of previously selected homes. The methodology used for collecting data allows extrapolating the information of a group of people and therefore generalizes the observed results to the target population studied. The analysis of a statistically significant sample allows making inferences or generalizing conclusions to the target population with a high degree of certainty. Results of the survey are processed using an urban data analysis approach.The most relevant results of the survey are presented on Section 6.3 using graphics, tables, and maps that allow characterizing distances, transportation modes, and other relevant features related to sustainable mobility in the studied zone.

Finally, Parque Rodó neighborhood was also analyzed using the TOD approach, a planning and design strategy for promoting urban development in a compact, mixed-use, pedestrian- and bicycle-friendly community, closely integrated with mass transit. This approach has helped many cities to reduce their carbon footprint while becoming more productive and more livable. The proposed methodology consists of two stages. In the first stage urban data analysis is applied to develop a spatial-functional definition of the studied area. The spatial-functional dimension is very important to identify, describe and analyze the organization and integration of the urban elements, especially those related to mobility and sustainable mobility. Spatial processes are developed through the analysis of spatial pattern, topology, and relevant indicators (e.g., socio-economic) and relevant mobility and accessibility conditions. Relevant functions are identified to characterize land use and the type of facilities in the studied zone. The second stage applies data analysis to characterize the current reality of mobility in the studied area, via relevant quantitative indicators related to the user experience when commuting from/to the studied area. The proposed methodology combines different quantitative indicators, qualitative evaluations and analysis to identify land uses and mix in the studied area, the connectivity provided by existing transportation means, and the infrastructure for bikers, pedestrians, and users of public transportation, with the main goal of improving accessibility and developing sustainable mobility in the area.

Three main sources of data were considered in the study of Parque Rodo. First, data were collected from Google Maps (downloaded in JSON format and processed using GIS software) and from personal inspection (using photographs taken in the studied area) to perform the spatial-functional analysis of the studied area. Second, operational data was gathered about public transportation (e.g., bus lines that operates in the zone, timetables, etc.) and also information about the available infrastructure (e.g., bus stops, bicycle lanes and bicycle parking facilities) was collected either from open data sources or by personal inspection. Finally, the study reported the most relevant information for the mobility analysis survey of Parque Rodó neighborhood and Engineering Faculty described in Chapter 6. Results of TOD analysis are presented in Section 7.3.

# Chapter 3

# Activities and risks

This chapter presents the work plan carried out in this thesis. It also states the risks arising from the research activities and proposes actions to mitigate their impact.

## 3.1 Work plan

This section describes the activities proposed by the project, with their respective tasks, milestones, expected results and deliverables.

### 3.1.1 Activity 1: analysis of the state of the art

*Task 1.* The tasks associated with this activity include: the prospecting and research of works and bibliography related to the thematic of sustainable mobility; the research and analysis of good practices of sustainable mobility implemented in other cities; and the theoretical and practical study of sustainable urban mobility.

*Objective.* This activity is linked to the objective of understanding the state of the art and literature related to the thematic of sustainable mobility.

*Milestone.* The milestone associated with this activity is the understanding the related work and main concepts of sustainable mobility.

*Expected results and deliverable.* The expected results of this activity include acquiring broad knowledge of advanced solutions for planning, operation and maintenance of transport systems and their integration into urban infrastructure; understanding the concepts of sustainable mobility; understanding the latest technological advances and innovative mobility systems that have achieved positive impacts in different cities of the world; and identifying the most effective measures for reducing the use of private cars. The deliverable associated with this activity is a document with the state of art describing the main contributions of each project or research analyzed.

### 3.1.2 Activity 2: Sustainable mobility initiatives in Uruguay

*Task 2.* The task associated with this activity includes the identification and characterization of the sustainable mobility initiatives developed in Montevideo.

*Objective.* This activity is linked with the objective of the characterization of the sustainable mobility initiatives developed in Montevideo and their commitment with sustainable development

*Milestone.* The milestone associated with this activity is the identification and analysis of all sustainable mobility projects that have been developed in Montevideo.

*Expected results and deliverable.* The deliverable associated with this activity is a document describing each sustainable mobility initiative and the main contribution to the city of Montevideo.

### 3.1.3 Activity 3: Sustainable Public Transportation Initiatives in Montevideo

*Task 3.* The task associated with this activity includes the characterization and the analysis of the sustainable public transportation initiatives in Montevideo through quantitative and qualitative indicators.

*Objective.* This activity is linked with the objective of the analysis and characterization of the sustainable mobility initiatives developed in Montevideo through public or private transportation companies.

*Milestone.* The milestone associated with this activity is the identification of sustainable mobility initiatives that are operating in Montevideo through public or private transportation companies.

*Expected results and deliverable.* The deliverable associated with this activity is a descriptive document, supported by sustainable mobility indicators, which enable characterizing sustainable mobility initiatives in Montevideo.

### 3.1.4 Activity 4: Study of the mobility demands on a specific zone of Montevideo

*Task 4.* The task associated to this activity involves performing a in-situ survey to citizens travelling regularly to/from the study area and collecting information of the universe of study in order to understand the mobility demand of the area and characterize citizens, their travels and their main mobility motivations.

*Objective.* This activity is linked with the objective to identify, analyze, and characterize the current situation regarding mobility and sustainable mobility in the studied zone, for different groups of people.

*Milestone.* The milestone associated with this activity is the identification of the means of transportation citizens use to travel regularly to/from the study zone in order to determine if citizens would be willing to change to more sustainable transportation modes and the specific issues that prevent them to make that change.

*Expected results and deliverable.* The deliverable associated with this activity is a document that present the collected information with an analysis and graphic representation of the main important information.

### 3.1.5 Activity 5: Integration of electric mobility in the sustainable mobility plan for a specific area of Montevideo

*Task 5.* The task associated with this activity involves working in coordination with project MOVES seeking to integrate the electric mobility in the sustainable mobility plan of a specific area of Montevideo.

*Objective.* This activity is linked to the objective of integrating electric technology into sustainable mobility plans, as a substitute energy for fuel.

*Milestone.* The milestone associated with this activity is the inclusion of electric mobility solutions into the sustainable mobility plan.

*Expected results and deliverable.* The deliverable associated with this activity is a document where actions or measures are defined in order to be included in the sustainable mobility plan, in coordination with MOVES project.

### 3.1.6 Activity 6: improvement of urban planning in the city

*Task 6.* The task associated with this activity includes studying urban planning measures and good practices related with sustainable mobility. Also, the analysis of urban infrastructure of a specific area in order to create more effective and sustainable travels.

*Objective.* This activity is linked to the objective of improving urban planning in the city in order to achieve more effective and sustainable travel.

*Milestone.* The milestone associated with this activity is the evaluation of measures and good practices of urban planning and the evaluation of the studied area in terms or urbanism and infrastructure in order to create a sustainable mobility plan for the area.

*Expected results and deliverable.* The deliverable associated with this activity is a descriptive document with the analysis of the studied area through an urban planning approach that promotes sustainable development.

## 3.2 Risk assessment and contingency plans

This section describes the risks identified for activities included in the work plan, explaining whether the risk occurred during the development of the thesis or not. For the risk that occurred, an explanation of the situation and how specific actions were applied to mitigate its impact is presented.

### 3.2.1 Activity 1 - Risk 1

The risk associated with this activity is related to the failure to address situations that might be of interest, or the impossibility to obtain all the information that would allow contextualized the proposal.

*Probability of occurrence*: low

*Probability of impact*: high

*Actions proposed in respond to the risk:* The risk is accepted, since the probability of occurrence is low. The thesis proposes working in coordination with professionals and organizations in the field of urban mobility and sustainable mobility to be able to study the subject from different approaches.

Activity 1 was successfully developed so the risk associated with this activity did not occur.

### 3.2.2 Activity 2 - Risk 1

The risk associated with this activity is not being able to contact professionals who can provide appropriate knowledge for the evaluation of sustainable mobility initiatives.

*Probability of occurrence*: low

*Probability of impact*: high

*Actions proposed in respond to the risk:* The thesis accept the risk as the probability of occurrence is low. One the other hand, most of the information are open in public sources.

Activity 2 was successfully developed so the risk associated with this activity did not occur.

### 3.2.3 Activity 3 - Risk 1

The risk associated with this activity is related to inaccessibility of data collection from the different public transportation companies.

*Probability of occurrence*: low

*Probability of impact*: high

*Actions proposed in respond to the risk:* The thesis propose to mitigate the risk by creating an agreement with the different public transportation companies in order to ensure data accessibility.

Activity 3 was successfully developed so the risk associated with this activity did not occur.

### 3.2.4 Activity 4 - Risk 1

The risk associated with this activity is related to not being able to obtain enough surveys because of the poor predisposition of people and therefore, it is difficult to characterize citizen.

*Probability of occurrence*: medium

*Probability of impact*: high

*Actions proposed in respond to the risk:* The thesis propose mitigating the risk by creating short, anonymous surveys, without asking for personal information. Also, it is important to tell people surveyed that this survey is enclosed in the framework of a thesis project and data collected are useful to characterize the accessibility of urban public transportation system of Montevideo.

Activity 4 was successfully developed so the risk associated with this activity did not occur.

### 3.2.5 Activity 5 - Risk 1

The risk associated to this activity is not being able to work in coordination with Project MOVES.

*Probability of occurrence*: medium

*Probability of impact*: low

*Actions proposed in respond to the risk:* The thesis accept the risk as the probability of occurrence is low. In case the thesis could not work in coordination with project MOVES, the thesis will continue working to reach their objectives taking data from other sources.

The proposed activities in coordination with project MOVES could not be developed satisfactorily. The main reasons of the occurrence of this risk were related to methodological differences in the conceptualization of a sustainable mobility plan. In the initial stages of this thesis, a meeting was held with those responsible for the MOVES project, with the main objective of exchanging ideas on sustainable mobility and proposing lines of joint work. Other contacts were attempted, especially to analyze the available data sources, but the MOVES project did not provide data for the development of the thesis. Subsequently, the other two points of contact were two working activities organized by the MOVES project. The first one was a meeting held at Engineering Faculty with the participation of a reduced group of students and professors. The meeting had the main goal of generating user-oriented activities, based on focus groups, to collect opinions and ideas for a sustainable mobility plan for Engineering Faculty. The proposed approach was not based on sound scientific methodologies, for example, expert knowledge was not adequately considered, and a survey for social networks was developed without a correct representation of the universe of the study; preliminary results showed large inaccuracies (for example, for the characterization of the typical person traveling to/from Engineering Faculty). Therefore, it was decided to develop and follow a methodological analysis based on scientific validations within the scope of this thesis. The second activity was a workshop related to sustainable mobility organized on December 2019 by project MOVES and supported by Euroclima+ (a cooperation program between the European Union and Latin

America that seeks to support the implementation of the commitments of the Paris Agreement in the area of climate governance). Although the workshop presented some valuable insights from a researcher in the area of sustainable environment and climate, no further actions were developed in this regard, because no data was made available for research and analysis. Thus, as planned in the risk mitigation strategy, it was decided to continue working on the thesis using data from other sources and developing a specific survey to collect data for the case study analyzed.

# Chapter 4

# Related work

This chapter presents a review of the main related works about sustainable mobility and TOD, developed in the world and Uruguay. Three relevant subjects are covered in the analysis of related works: the main concepts and researches about sustainable mobility, the main concepts and works related to TOD, and sustainable mobility initiatives recently developed in Uruguay.

## 4.1 Sustainable mobility

This section reviews the main concepts and work related to sustainable mobility.

Modern cities are conceived to support different transportation modes, which are supposed to coexist, interoperate, and share the urban space. To guarantee a proper support for intermodality, transportation modes are supposed to be well integrated and connected, thus providing citizens with efficient and effective mobility (Xiong et al., 2012). However, the transportation planning problem is usually driven by traditional approaches that simplify, or even ignore, the complexity of handling several transportation modes coordinately. As a consequence, administrators often fail to provide holistic plans, accounting for all transportation modes operating in the city and including a comprehensive decision-making to consider indirect and interrelated impacts of the implemented solutions. Approaches that do not consider the city and transportation systems as a whole lead to isolated actions that usually result in poor and inefficient policies, which fails to solve the main problems related to mobility, among them, sustainability.

Litman and Burwell (2006) established the relationships between sustainable transportation and mobility and recognized that in order to achieve sustainability, transportation must be conceived from a broad point of view to consider energy efficiency, health, economic and social welfare, and other relevant aspects related to sustainable development. Transportation impacts on sustainability were characterized into three broad areas (economic, social, and environmental) and it was stated that the correct approach for solving the underlying issues is to find strategies that help achieving all the main goals (in the long-term) by increasing transportation system efficiency. Several perspectives for addressing the sustainability problem in transportation were reviewed, and a list of common indicators for sustainable transportation was presented. Approaches for sustainability in transportation include improved travel choices, pricing and road design incentives, proper land use, energy efficiency, ecological integrity, human health, and technical improvements to motorized vehicles, among others. A paradigm shift Litman (1999) was proposed for rethinking transportation, considering different integrated solutions for sustainable transportation systems.

Sustainable urban mobility planning begins with designing a strategic plan for the community. Banister (2008) put special emphasis on stakeholder participation in the planning process, to involve them in the reasoning and implementation of specific initiatives for sustainable mobility. After questioning conventional principles for transportation planning, seven key elements for sustainable mobility were discussed and a more flexible paradigm to meet sustainable mobility purposes was proposed. Banister concluded that proactive involvement of relevant actors (including academia, policy-makers, and others) is crucial and more effective than traditional approaches for sustainable mobility. In this regard, specific changes must be made regarding land utilization, environment, public health, and ecology. In turn, actors must accept their collective responsibility to achieve an effective sustainable mobility model to overcome car dependency. In particular, stakeholders must be engaged to support the application of measures towards promoting the main goals of sustainable mobility.

Methodological analysis and indicators have been studied as useful tools for the evaluation of sustainable mobility in cities (Rodrigues et al., 2008; Gudmundsson et al., 2016; Johnston, 2008). Relevant studies are those related to understand the evolution of current transportation systems towards sustainable one, and those that evaluate the impact of selected solutions for specific case studies. In this context, indicators are used to simplify complex phenomena and to provide hints of different issues or problematic situations (Maclaren, 1999). The combination of multiple indicators also allows capturing different dimensions and aspects of sustainable mobility.

The main concepts about indicators for sustainable transportation were presented by Gudmundsson et al. (2016), focusing on the role and importance of quantitative and qualitative indicators for stakeholders (including decision-makers, planners, and operators). Frameworks for assessing sustainability metrics were reviewed, and a framework towards sustainable transportation was proposed. Two case studies were presented: European transportation and high-speed rail in England. The main conclusions from the case studies is that indicators and frameworks strongly depends on the context. Thus, understanding the context is key for succeeding in implementing effective sustainable mobility actions. Solid frameworks can stimulate politicians, decision-makers, and citizens to cooperate in the implementation of practical efforts regarding the studied topic.

Miller et al. (2016) studied the role of public transportation regarding sustainability, reviewing related works that analyzed case studies of sustainable transportation. Frameworks, key challenges, and the benefits of public transportation were analyzed considering the three dimensions from sustainable development (environment, economy, and society). The reviewed articles were characterized regarding the main considerations for each of the studied dimensions. Finally, a set of recommendations were provided for developing and planning sustainable public transportation systems.

Rodrigues da Silva et al. (2010) developed an index of sustainable urban mobility including several important features previously identified by Litman (1999) for comprehensive and sustainable transportation planning. The index is based on data obtained from planners and includes weights for different criteria, defined by experts. An application was presented for the city of São Carlos, Brazil, a medium-size city with 250,000 inhabitants. A basic analysis was proposed to demonstrate the viability and the efficacy of the proposed index. The main results of the study indicated that the proposed index was relatively easy to compute and flexible enough to be applied to characterize sustainable mobility.

Johnston (2008) developed Production, Exchange, and Consumption (PECAS), a comprehensive method for modeling the impacts of transportation, to be included in an integrated urban model of California. PECAS was conceived as an spatial economic urban model, combining Walrasian concepts and random utility theory, using a network and a zone-based travel model to provide a theoretically valid measure of regional and statewide utilities. PECAS provides several data of economic utility like households by income, housing rents, housing affordability, etc. Several major transportation scenarios were studied, including metropolitan planning organizations of California, Sacramento, and San Diego. The metric evaluated included greenhouse gas emissions, air pollution, and economic welfare and equity. Results of the analysis were reported as relevant to state and regional transportation plans.

Baidan (2006) studied the main problems of public transportation in Bucharest, Romania, which are similar to other capitals in Eastern Europe (e.g., the lack of policies to discourage car use, the lack of intermodal transportation options, etc.). Public transportation in Bucharest was analyzed through an accessibility indicator, considering the fares and the access of new residential areas to the transportation system. The main results of the study indicated that Bucharest has the cheapest public transportation fares among post-socialist European capitals, and that even though the metro does not cover many of the new residential areas, most of the citizens living there do have access to surface public transportation. A relevant suggestion was formulated, proposing the creation of intermodal hubs; networking the local/regional train systems with the metro; and providing other services as Park&Ride, bicycle parkings, rental services, etc., to promote sustainable transportation to citizens.

The successful case of sustainable mobility in Bogotá, Colombia, was analyzed by Lyons (2017). The study focused on specific actions oriented to address the protection of the environment and achieve both economic and social sustainability via a non automobile-centric approach. To satisfy the mobility needs, the city administration developed a mobility strategy based on three pillars: (i) discouraging the use of the car; (ii) the promotion of bicycle and walking as transportation modes; and (iii) the construction of an efficient public transportation network, anchored by a Bus Rapid Transit (BRT) system. Bogotá integrated transportation planning with social planning, by designing open areas and housing plans accessible to public transportation. According to Lyons, the results of the actions made in Bogotá span the three pillars of sustainability: economic, social, and environmental. Some of the outstanding results for the case study of Bogotá include BRT reduced travel times in 32%, 9% of former car drivers switched to BRT, traffic accidents reduced 93%, and air pollution decreased 40%. Overall, the study argues that the Bogotá case demonstrated that BRT is a viable and realistic solution as urban transportation plan, and also that increasing infrastructure for bicycle and walking is a viable strategy to promote sustainable transportation modes. The author concluded that the case study of Bogotá can be replicated in other developing countries, on the path towards sustainable transportation.

Moreover, in Latin America, Rodrigues et al. (2008) studied the provision of transportation services in Brazil following a specific methodology based on workshops with public managers and planners to characterize sustainable urban mobility. Multiple criteria analysis was applied to give support for decision-making, in order to identify proper goals, evaluate their relevance, and assess the impact of different solutions. Four stages were applied: (i) characterization of the problem; (ii) identification of relevant elements (including accessibility, congestion, infrastructure, social inclusion, pollution, non-motorized modes, and others); (iii) construction of a cognitive map, using operational and strategic concepts to reach the objectives; and (iv) identification of key viewpoints, using relevant concepts from the cognitive map, according to decision-makers. A series of workshops were performed in eleven Brazilian cities to gather information. Results were grouped by geographical regions, focusing on capturing different dimensions of sustainability in the context of each region, regarding three dimensions: social, economic, and environmental. The main identified problems were related to the relevance of urban public transportation, infrastructure, and environment. The importance of social, economic, and environmental issues reflected the development of each studied region. In conclusion, Rodrigues et al. stated the importance of the applied methodology to capture different views of sustainable mobility in Brazil and its application for creating public policies in that regard.

## 4.2 Transit Oriented Development

This section presents the reviews of relevant works related to the TOD paradigm.

Raising awareness and involving citizens are key aspects for sustainable mobility. Technology has been identified as one of the most valuable tools to help developing environmental friendly sustainable mobility. Different methods and indicators have been proposed to analyze means of transportation (Gudmundsson et al., 2016) and other important issues related to sustainable mobility. Some of the proposed indicators for detecting trends, assessing and comparing activities, and evaluating policies related to sustainable mobility, are those considered in TOD principles. In the related literature, TOD is conceived to hold urban sprawl, prioritizing sustainable mobility as well as driving to environmentally and economically-balanced growth (Qvistrom et al., 2019). TOD is closely related to the smart growth and new urbanist approaches (Burchell et al., 2000) conceiving walkable, compact, pedestrian-oriented, and mixed-use communities centered around high quality public transportation systems (Sung and Oh, 2011) reducing, in this way, the utilization of automobiles. One the one hand, successful examples of applying TOD in USA, Europe, and Asia, are commonly associated to mass rail systems. On the other hand, in Latin America, most of the TOD-related initiatives have been implemented on BRT or similar public transportation systems, which allow providing a cost-effective service more adapted to the economic reality of developing countries.

Hasibuan et al. (2014) studied the applicability of TOD ideas for improving urban mobility in a case study in Jabodetabek, the largest metropolitan area in Indonesia, with more than 27 million population. The analysis focused on relevant sustainable development indicators, including ecological footprint, carbon emission, and green open space. The main results of the analysis showed that TOD concepts can definitely contribute to restructuring urban land use and growth, improving the modal share of public transportation, and also improving the quality of the whole urban environment.

Based on TOD principles, Loo and Du Verle (2016) proposed a sustainable mobility approach oriented on people and places. The need of shifting transportation modes to promote sustainability was highlighted and three lines were proposed for TOD planning. The first line focused on the built environment at both neighborhood and city scales; the second line proposed not only improving public transportation, but also walking and related urban planning/design related to public spaces and greenery; the third line encouraged non-uniform designs for different neighborhoods, considering relevant indicators for the local geographical context.

A case study in the city of Hong Kong, China, was presented, analyzing several indicators for five different neighborhood types. The authors recognized that further efforts are needed to quantify and fostering both direct and indirect benefits associated with TOD, benefits beyond traditional impacts on transportation. Tsigdinos et al. (2019) presented an analysis of the zones surrounding stations of the metro line 4 in Athens, Greece, regarding TOD considerations and ranking the stations according several quality indicators, regarding density, walkability, public transportation, land uses, and public spaces. The applied methodology combined spatial analysis, definition of ten proper quantitative indicators for categorizing TOD regions, multicriteria analysis for ranking the studied location, and geo-visualization of the results. The analysis allowed identifying significant differences between categories and also a contrast in terms of TOD indicators between central ans suburban stations. The authors found important limitations of the studied areas and common weaknesses of more than a half of the studied stations, which hinders the implementation of integrated transportation and urban planning strategies. Specific suggestions for improving the identified weaknesses were also proposed.

Woo (2021) evaluated characteristics related to the TOD paradigm in Seoul, Korea, to characterize different TOD types of subway station areas and their neighborhoods, for a urban rail transit developed considering TOD concepts. The article applied accessibility analysis and clustering methods and categorized TOD types using the targeted 246 subway station areas at the neighborhood level. The main results of the analysis grouped the studied zones in four categories, accounting for different density levels: (1) high-density characterized by mixed-use areas for residential and retail purposes, which have good accessibility; (2) moderate-density, with average accessibility and high-mixed land use; (3) compact business, mainly used for offices and commerce and having a high accessibility and also a high transit demand; and (4) compact housing with high-rise buildings mostly used for residential purposes. In turn, the study also concluded that the period of urban development significantly affects the main features of each identified category. Finally, authors suggested that category (2) offers the best option for urban redesign under TOD concepts.

In Latin America, developments related to the TOD paradigm have been scarce. The region mostly focused on building and developing transportation infrastructures based on mass transit corridors and BRT systems. Some articles have argued that BRT systems, even though applying a more restricted paradigm, are able to produce a similar impact on land utilization than TOD strategies (Cervero and Dai, 2014). However, Moscoso et al. (2019) studies of the impact of BRTs on land use are not necessarily related to TOD, and that Latinamerican cities have considered BRT as a mobility solution, without integrating key TOD concepts to promote compact, dense, and well-connected urban development. Nevertheless, the most well-known BRT development in Latin America (Curitiba, Brazil) is also a model of TOD, as a result of applying an innovative planning approach oriented on BRT and exclusive public transportation corridors. The land development impacts of BRT have been also studied in other Latinamerican cities, such as Bogota and Quito (Bocarejo et al., 2013; Rodriguez et al., 2016).

Other analysis of sustainable transportation considering TOD-based indicators have been developed for specific cases, such as the study for universities in the Guadalajara metropolitan area, Mexico, by Alba et al. (2020).

## 4.3 Sustainable mobility initiatives in Uruguay

This section presents sustainable mobility initiatives in Uruguay that have been developed since sustainability has declared a global concern.

### 4.3.1 Urban mobility plan of Montevideo

In 2005, the City Hall of Montevideo (IM) initiated a proposal for a urban mobility plan (Intendencia de Montevideo, 2008), with the aim of creating a Metropolitan Transportation System (STM) organized around exclusive public transportation corridors. The mobility plan presented by the IM included a restructuring and modernization in the public transportation system, freight, and logistics, prioritizing public and non-motorized transportation and provide a safe, accessible, efficient and sustainable transportation system with low environmental impact.

The plan enclosed two stages: stage 1 (2008–2010) built two exclusive segregated corridors and their terminals, and stage 2 (2010–2020) built four additional segregated corridors and their terminals. In addition, the plan included integrated transit management measures; passengers information systems, technology improvement (GPS in buses, pre-paid smart card for payment, centralized STM information); integrating the fare collection and operation systems; creating a mobility observatory; and creating of pedestrian paths and bicycle lanes network to promote sustainable mobility in the city. The mobility plan required several professionals (architects and engineers) specialist in the field of mobility and urban planning. It implied a radical change for the Metropolitan Transportation System, with a costly implementation.

Initially, a first line of work was carried out on Garzón Avenue to validate the solution of the segregated corridors. However, instead of accommodating traffic, the project generated more congestion and increased the dissatisfaction among citizens. The generated traffic disorder led to re-evaluate other objectives that the mobility plan had, culminating in the disruption of several of its planned works. Overall, the mobility plan had positive impacts with the introduction of the STM smart card, GPS in buses, and centralized STM information, which improved the quality and user experience of the public transportation system of Montevideo. The data collected from STM are now used for further research to improve urban mobility.

Actually, IM is promoting active mobility with the aim of providing citizens a more accessible and safe place in urban mobility. Regarding this, new bicycle lanes were built in different zones of Montevideo and the existing ones were improved. In addition, IM incorporated in their headquarters a bicycle parking for their employees to promote the use of bicycles. Since 2019, this thesis has been in contact with IM, exchanging useful data and information related to sustainable mobility in several instances. In 2019, in a personal interview with Juan Vespa and Patricia Abreu (architects responsible for the mobility plan in IM, who reported that IM is developing actions to promote active and sustainable mobility (Hipogrosso, 2019). Among other activities, the project is working on the expansion of the bicycle lane network, transit regulations, and installing more bicycle parkings. However, at the present time (September 2021), there are still actions to be carried out, including the mandatory regulations for bicycle parking in public and private buildings that are intended to be carried out at the beginning of the next year (InfoNegocios, 2021).

In the framework of this thesis, the mobility plan proposed by IM is considered as a first approach to sustainable mobility in Montevideo. The implementation of the mobility plan project had positive experiences, and had underline that improvements are still needed in the urban transportation system of Montevideo.

### 4.3.2 MOVES project

In Uruguay, project "Towards an efficient and sustainable urban mobility system in Uruguay" (URU/17/G32, acronym: MOVES) was launched in 2017, as a joint effort of government and transportation companies. The main goals of the project are defining regulations for low-carbon transportation systems, evaluating clean technologies in Montevideo, and promoting a cultural change towards sustainable transportation modes.

Many organizations have been involved in MOVES project: it is funded by the Global Environment Facility, implemented by the United Nations Development Program and executed by MIEM, in association with the Ministry of the Environment and the Ministry of Housing and Territorial Planning, with the collaboration of the Uruguayan Agency for International Cooperation. With the main goal of reducing carbon emissions, MOVES project seeks to promote the use of public transportation and active mobility (walking and cycling). Regarding clean technologies, the project suggested changing the public transportation system, cargo, and last mile vehicles, to use electric and more sustainable means. Finally, to promote a cultural change towards sustainable transportation modes, the project works on improving the quality of service of public transportation, the incorporation of mobility in urban planning processes with the objective of revitalize public space to obtain more livable cities, and also supporting institutions through the generation of regulations and taxation to vehicles that do not favor sustainable mobility.

Regarding sustainable mobility plans for neighborhoods or specific zones of Montevideo, MOVES have developed some initiatives, but focused on small and isolated cases, such as the Institutional Plan for Sustainable Mobility developed at the Uruguayan office of the United Nations Development Programme, with the goal of motivating people to adopt healthy mobility habits. This initiative developed a guide for planning sustainable urban mobility in Uruguay (MIEM, 2020), with the main goal of providing governmental institutions a framework for a proper planning of sustainable mobility in cities and territories. The guide covers general concepts of mobility, mobility planning, sustainable urban mobility measures to be applied in cities, and sustainable urban mobility elements design guide. In turn, a toolkit for designing and implementing institutional plans for sustainable mobility was developed to promote more sustainable trips to/from small and medium-size organizations. However, the tool has some drawbacks, since it is specifically focused on the user: it proposes applying design thinking to conceive non-formal proposals, often emerging from the participation of small discussion groups. This methodology is not properly conceived to capture all the relevant aspects of sustainable mobility, since only a small, non-representative, of voluntary participants are taken into account (i.e., far from the proper sample size of the involved people to draw proper conclusions), and expert knowledge is not considered in the discussion groups. Design thinking has been promoted as a useful approach for conceiving innovative solutions, but in this case the focus is not on providing a real solution for the problem, considering the current state of mobility in Montevideo and the reduced participation on the studies. Although the toolkit contributes to raise relevant issues about sustainable mobility, the proposed institutional plans are very low-impact initiatives, e.g., in some cases involving less than 20 persons that commute to workplace (MIEM, 2020). A greater commitment from institutions and more solid analysis are needed to conceive and implement measures with greater impact. Other minor initiatives related to sustainable mobility have been developed in the context of MOVES project, such as replacing (non-sustainable) delivery vehicles for electric tricycles and electric pedal-assisted bicycles and incorporating electric utility vehicles for cargo companies, but without proposing or implementing a comprehensive sustainable mobility plan for each case.

In the initial stages of this thesis, some ideas were proposed for joint development with project MOVES. An initial meeting was coordinated to know the main lines of their work, to determine possible contributions of the thesis to the project. Also, we participated of two workshops they organized with the group in charge of the toolkit for designing and implementing institutional plans for sustainable mobility. However, it was not possible to advance in joint developments due to the different methodologies proposed for the studies. This thesis proposes developing a research based on a methodological analysis applying quantitative and qualitative indicators, scientifically validated in relevant related works from literature, considering both expert knowledge and the opinion of citizens gathered on in-situ interviews in the studied area, and considering a proper sample size of the universe of study.

### 4.3.3 On-demand mobility initiatives

Since the emergence of sustainable mobility, there has been a booming of new, innovative mobility services worldwide, seeking to offer people more options to commute in urban transportation. Mobility on Demand (MoD) is a new alternative solution of personal mobility that responds to passengers' demands in real time. Using advanced technologies and dynamic pricing schemes, people can plan their journey by choosing among several possible routes and transportation means. Electric scooter, pubic bicycle and car sharing are MoD solutions. These transportation means focus on providing appropriate solutions for mobility, to alleviate the impact of typical problems such as the lack of space and parking, acoustic and environmental pollution, etc. Government support is necessary for these models of mobility to operate. In addition, it is essential to design and build suitable urban infrastructure for mobility and parking. Finally, the integration of MoD to existing urban transportation system is needed to improve the transportation service of the city and offer multi-modal mobility options to citizens.

The electric scooter is a new mode of urban transportation that has gained popularity all over the world as an alternative to driving. Electric scooters provide an environmentally friendly alternative for short journeys (micromobility) that are either too far to walk, or too close to drive a car, to be a cost-effective option. Three companies of electric scooter (Grin, Lime, and Movo) operated in Montevideo since 2018, but nowadays the three of them stopped operating since December 2019. Grin operated with an application where electric scooters and electric scooter stations were shown in a street map of Montevideo. The electric scooter stations were parking places where the company parked scooters, with the permission of a close local business or an institution. Stations also provided a connection to the electric grid to charge scooters. The service provided a practical and easy way to use electric scooters: by simply downloading a mobile application and setting up a payment method, users had access to a network of scooters that they can use at any time. Electric scooters had GPS blue tracking, so users were never too far from picking up a electric scooter and they could leave it anywhere within the area where the service had operated. To reduce logistic efforts of collection, distribution, and charging, Grin had incorporated scooter stations after negotiations with drug stores, education centers, parking lots, and other commercial businesses around the city. Nevertheless, people continued parking the scooters in any place. Up to December 2019, the company did not apply any penalty fee for not using the stations.

Despite the rapid growth and expansion of electric scooter, they have created traffic disturbances on cities where they are installed, and even some fatal accidents due to the lack of regulations (Perry, 2020). Different regulations and legislation measures have been proposed internationally, and in some countries as Great Britain and Monaco, electric scooters are illegal. In Montevideo, a total of 700 electric scooter had been circulating through the city. However, the business model of the electric scooter did not work for any of the three companies and after a year they left the Uruguayan market.

Public bicycle system is another mobility model on-demand very popular around the world that makes positive contribution to sustainable mobility. In 2015, the City Hall of Montevideo introduced a public bicycle system, called *Movete*, as part of the urban transportation system to promote green mobility and a healthy way to know the city, move to workplaces, or simply extend the accessibility of public transportation systems to final destinations. As of December 2019, the public bicycle system consists of a fleet of 80 bicycles spread in a network of eight automated stations, distributed from the Old City to the Center neighborhoods. Bicycles can be rented at one station and returned in another station in the coverage area. A card of the integrated Metropolitan Transportation System (STM) is required to rent a bicycle in Movete and people that do not own a STM card, e.g. tourists, can obtain it with no charge in the center office of Movete. Users cannot use the bicycle service for more than four hours per day. The service has a time limitation for users, which cannot use the bicycles for more than four hours per day. This limitation is in line to promote more people have access to use the service. The city administration is planning to expand the coverage (i.e., the area of operation) of the public bicycle service in 2020. The expansion is planned to include 60 stations and 600 bicycles, in order to increase accessibility and promote active mobility. New neighborhoods near the city center will be covered by the service, including Cordón, Parque Rodó, Parque Batlle, and Tres Cruces, accounting fora significant larger population then in the current implementation of Movete. Despite city administration effort for the implementation of this project, this initiative has not been executed yet.

Finally, one of the concepts that has revolutionized mobility worldwide in the last few years is carsharing. The recently proposed hybrid car sharing services provide citizens a mean to rent cars on-demand, for short periods of time. Car sharing systems are developed to be accessed through a mobile application that allows users to choose from different locations to pick up and return the car, and establish the time they will use the service.

Carsharing was originally proposed in Switzerland in 1987 and gained adherents in many other countries (Becker et al., 2017). Asia is the continent with the highest percentage of registered users of the car sharing service (58%), followed by Europe (28%). Five characteristics demonstrate the recognized success of *carsharing* service model in Madrid, according to the site elEconomista.es (2018). First, the use of electric cars in carsharing fleets helped reduce air pollution. According to data shared by Daimler AG company, there was a reduction of 1,638 tons of $CO_2$ by the end of 2017 as a result of the introduction of electric car on carsharing fleets in major cities (Car2go, 2018). Second, carsharing companies that use electric cars are exempt from paying parking fees on public spaces, which makes it more convenient for citizens than using private cars. Adittionally, the carsharing fleets have small car models that facilitates parking in the city. Third, the use of the car-sharing service has significantly reduced congestion in the city, thanks to the decrease in the number of cars in circulation. Fourth, carsharing promotes the concept of the collaborative economy, giving users the possibility of acquiring a car without having to pay for their maintenance costs and ensurance. Finally, booking and accessing to the mobile app in carsharing service is very easy; this is another reason why drivers are increasingly using the service in their daily trips.

The car sharing facilitator is a car brand (e.g., Toyota is one of the car brands providing this service in Montevideo). To promote the use of the hybrid car sharing service, the Uruguayan government has exonerated parking costs in the city for this transportation mode. Carsharing is a very new service in Montevideo, which started operation in the last months of 2019 and did not gain major acceptance in 2020, mainly because traffic reduction due to the COVID-19 pandemics. Thus, there is not enough information or data to perform an in-depth analysis of this mobility mean.

### 4.3.4 Electric mobility initiatives

Electric mobility is another initiative that goes in line with sustainable mobility and has been developed in Montevideo recently. Two initiative have been developed in the city: electric bus and electric taxis.

#### 4.3.4.1 Electric Bus (Pilot Plan)

As in most countries in Latin America, Uruguay has recently prioritized moving towards cleaner energies in public transportation, in order to reduce its carbon footprint. For the last few years, transportation authorities in Uruguay have studied the potential benefits of including electric vehicles to the public transportation fleet in Montevideo. As a result, the Uruguayan government requested a loan from the Green Climate Fund, the entity that operates financial mechanisms to assist developing countries in adaptation and mitigation practices to counter climate change, in order to facilitate the modal shift from diesel to electric buses and allow Montevideo to replace 10% of the bus fleet (Acosta, 2014).

The main public transportation company operating in Montevideo is CUTCSA, accounting for about two-thirds of the market share and also of the buses operating in the city (CUTCSA, 2017). CUTCSA has conducted tests of mobility using electric buses, with incentives and support from the Ministry of Energy and the city administration of Montevideo. Since 2017, a pilot plan is in course, using one electric bus that operates in different lines (the line changes weekly) to test the performance of this new transportation mode. The electric bus used in the pilot plan is a fully electric (no emissions) ByD vehicle, model K9A, with an autonomy of more than 250 km. It has an environmental friendly long-life iron phosphate battery of 324 kWh that admits more than 6000 charge cycles, and demands 3.5 h for total fast charge. The maximum speed of the bus is over 90 km/h and the average consumption is 100 kWh each 100 km. The pilot plan using electric bus has been considered an important advance for public transportation system of Montevideo. The new buses incorporates air conditioning to keep the environment ventilated, has decreased motor sounds and vibration, and offers universal accessibility, which is a great improvement in particular to those people with reduced mobility.

In May of 2020, thirty electric buses circulated on Montevideo with the purpose of gradually evaluating their operation and integration to the existing public transportation system. At the beginning of 2021, two more electric buses started to operate in the department of Canelones, Uruguay. The goal of the IM is to reach 120 new electric buses to the transportation system of Montevideo in the following years (MIEM, 2021).

#### 4.3.4.2 Electric taxis

The electric taxis initiative is in line with the main idea of government entities to promote using energy efficiency in public transportation, which have promoted the shift to more renewable energy sources, especially since 2015. As the change from gasoline to electric implies a higher initial investment, it is more profitable on taxis, which run many kilometers and the investment can be compensated with the lower operating cost. Currently, 54 taxis circulate on the streets of Montevideo and the main goal of the city administration is to increase the fleet of electric taxi to 300 vehicles (10% of the total fleet of taxis) (Presidencia de la República, 2018).

### 4.3.5 Promotion of walking and discourage the use of private motorized vehicles

Besides the aforementioned sustainable public transportation and sustainable mobility initiatives, other actions have been performed by the city administration to promote pedestrianism and reduce the number of private motorized vehicles in circulation in Montevideo.

#### 4.3.5.1 Pedestrianism

Walking is the most sustainable transportation mode because is the only one that does not depend on any device or service. In Montevideo, multiple initiatives have promoted and stimulated pedestrianism; among the most relevant ones we can mention that walking lanes were incorporated in several parks, several streets in different neighborhoods (Old City, Reus, and even in low-income peripheral suburbs) were transformed for pedestrian-only use, and the constant reparation of sidewalks in a joint initiative (the Sidewalks Plan) with the participation of the municipality and residents. "Old city at human scale" was a relevant project to improve pedestrianism, which involved several infrastructure modifications. Focused on the Old City neighborhood, the aim of the project was revitalizing the historic center of Montevideo, promoting sustainable mobility, universal accessibility, and improvement of public space (Intendencia de Montevideo, 2015). Several important tasks were developed within the project, including repairing, widening, and transforming sidewalks to single pavement; incorporating access ramps in every corner to improve accessibility; renovating the public lighting to improve safety; highlighting historical buildings and renewing urban equipment (street and square benches, litter bins, gardening, and signs, which were unified to give more information to the user); and building new rest areas, as suggested by neighbors. The project involved other activities related to improving tourism services, environmental management, renovation of buildings that were badly damaged, and the incorporation of bicycle lanes all around the historic center. The project achieved positive results, thus improving accessibility, comfort on walking, safety, urban equipment on public spaces, and sustainability of the area.

#### 4.3.5.2 Discouraging the use of private motorized vehicles

There is a rising concern about the impact of automobiles in the urban mobility area, which cause air pollution, human health effects, global climate change, congestion, and noise pollution. In order to achieve sustainable mobility, it is not enough to promote sustainable transportation modes; specific policies to limit the use of private motorized vehicles must be applied too. In this regard, the city of Montevideo has also proposed several measures to discourage the use of cars, thus contributing to sustainable mobility. Some policy measures applied include bus-only and preferential lanes for buses and taxis were deployed in many avenues, to promote the use of public transportation; tariff zones were applied for street parking in districts with high traffic and congestion (Old City, Downtown, and Cordón neighborhoods), the development of new sustainable transportation modes has been considered (e.g., an electric train connecting the city center with the Eastern part of the city) to reduce the dependence on automobile, the integrated public transportation system of Montevideo has recently incorporated taxis. All these measures are in line with the efforts to reduce car utilization. Furthermore, the administration has recognized the importance of promoting a cultural change, for citizens to do a responsible car utilization. Furthermore, project "Old city at human scale" also discouraged the use of the automobile, taking away street space to give it to urban equipment and pedestrianization.

Other relevant measures, such as private traffic restrictions, which play a significant role in urban transportation regarding accessibility, air quality, and other factors that affect the quality of life of citizens (Shaheen and Cohen, 2018), have not yet proposed nor implemented in Montevideo.

### 4.3.6 Public transportation system and universal and sustainable accessibility

Accessibility is a crucial concept in nowadays smart cities, to guarantee a proper mobility, citizen participation in social, economic, and cultural activities, and an overall good quality of life. In Uruguay, recent projects have studied and processed different available data sources to characterize the accessibility provided by public transportation system. Two relevant projects studied the accessibility of public transportation systems in the city of Maldonado and the other for the city of Montevideo. These projects are described in the next subsections.

#### 4.3.6.1 Public transportation and accessibility to education centers in Maldonado, Uruguay

Several data sources were studied for the city of Maldonado to gather information to characterize the public transportation system of the city. As a relevant case study, the accessibility to education centers was analyzed (Massobrio et al., 2021). In order to quantify the provision of the transportation system in the metropolitan area, a matrix of travel times between different areas of the city was computed. Trips in different modes (walking, with a direct bus line, and trips involving transfers) were considered. Then, geo-located data about public services were used to compute the accessibility offered by the public transportation system. The accessibility to education centers was computed, as it is a relevant public service for the Municipality of Maldonado. Finally, an interactive visualization tool was developed to graphically display the computed information. The accessibility indicator constitutes an input for transportation authorities, to provide assistance for decision-making in the studied area. It also allows identifying potential inequity situations related to the public transportation system in the city.

#### 4.3.6.2 Spatial, universal, and sustainable accessibility: characterizing the multimodal transportation system of Montevideo, Uruguay

Current project (code FSDA_1_2018_1_154502), funded by Fund for Research from Open Data, National Agency for Research and Innovation, Uruguay, proposes developing a characterization of urban accessibility, as an important tool to determine the quality and equity of transportation systems and the impact on daily activities of citizens. Several data sources are studied to characterize the accessibility of the transportation system of Montevideo. Three dimensions are considered in the analysis: territorial, universal, and sustainable accessibility. Territorial accessibility analyzes existing mobility alternatives to identify potential accessibility problems that prevent the participation of citizens in social and economic activities. The universal dimension studies accessibility problems of transportation systems for people with reduced mobility and the elderly, the alternatives of universally accessible transportation modes, and the identification of points of interest that are not universally accessible. Finally, regarding the sustainable dimension, sustainable mobility options offered by the city are studied, including non-polluting and low emission vehicles. A fourth dimension is proposed for the study, transversal to the previous three, to assess the impact of the socioeconomic condition on the three accessibility dimensions studied. It is expected that results from the project will be useful for the authorities, transportation companies, academia, and civil society in general, to identify situations of inequality in access to the different modes of transportation in the city.

## 4.4 Summary

The analysis of related works allows concluding that there are several articles reporting studies and projects developed in many cities around the world focused on the matter of sustainable mobility. The large number of articles and reports demonstrate that sustainable mobility is a growing worldwide concern.

In the last five years, Uruguay has followed the trend of more developed countries regarding sustainable mobility, developing several initiatives oriented towards a more sustainable development paradigm, with less consumption of $CO_2$ and healthier lifestyles.

Regarding sustainable mobility, the major problem on modern cities is to coordinate all the transportation modes that operates in a city considering their direct and indirect impacts. As a consequence, some authors as Litman (1999) and Banister (2008) proposed a paradigm shift on transportation systems that involves the integration of sustainable transportation solutions and stakeholders (including academia, policy-makers, and others) in the planning process to support the change. Furthermore, several methodological analysis and indicators have been proposed in the evaluation of sustainable mobility in cities as useful tools to simplify complex scenarios and avoid problematic situations. The combination of multiple indicators illustrates different dimensions and aspects of sustainable mobility. Another key aspect of sustainable mobility is the design of the urban environment, raising awareness of environmental pollution and involving citizens to live healthier by promoting, in turn, sustainable transportation modes. TOD is conceived as a new urbanist approach (Burchell et al., 2000) that promotes walkable, compact, pedestrian-oriented, and mixed-use communities, centered around high quality public transportation systems (Sung and Oh, 2011). Successful examples of the application of TOD have been developed in USA, Europe, and Asia, commonly built around mass rail systems. In Latin America, most TOD applications have been implemented around BRT or similar public transportation systems, due to the economic reality of developing countries.

The first initiative related to sustainable mobility in Uruguay appeared with the proposal of Urban mobility plan of Montevideo presented by the City Hall of Montevideo (IM) in 2008. The plan enclosed multiple activities but only few of them were executed. The major contribution of the plan was the introduction of the smartcard STM (Metropolitan Transportation System), GPS in buses, and centralized STM information improving the quality and user experience of the public transportation system of Montevideo. The data collected from STM is a useful information for research related to urban mobility.

Uruguay joined in 2017 the parternship for action on green economy (PAGE), a programme for joint collaboration between five United Nations agencies and regions/countries around the world, which involve the integration of sustainable, inclusive, and green development into the core pillars of economic development. The first project launched since the joined with PAGE was MOVES project, with the support of government and transportation companies. The main goals of the project were reducing carbon emissions by evaluating clean technologies and promote a cultural change towards sustainable mobility. The project proposed several initiatives that pretends to have a big impact on transportation system and carbon emissions of our country. However, the transition from carbon to electric vehicles is a low process that implies higher initial investment and changes on logistics and operations from transportation companies. Regarding sustainable urban mobility initiatives, the project proposed a mobility plan guide for institutions without capturing all relevant aspects of sustainable mobility.

With the emergence of sustainable mobility new alternative solutions of personal mobility appeared. Electric scooter, pubic bicycle, and car sharing are on-demand mobility solutions that responds to passengers' demands in real time and combines advanced technologies and dynamic pricing schemes. Electric scooter service at first pretend to be a simple solution for last mile trips, however, the lack of regulation have created traffic disturbance and even some fatal accidents in the cities were they are installed. On the other hand, public bicycle has gained many users around the world and makes a positive contribution to cities. Additionally, carsharing is a another mobility service very popular in many countries that helped reducing air pollution, but the business model responds better on larger cities where parking fee on public places and congestion is higher than in our country. In Uruguay, carsharing is still on an initial stage.

Electric mobility is another initiative proposed to decrease environmental pollution. Two electric initiative have been developed in Montevideo: electric bus and electric taxis. Both initiatives have government support, but electric bus is in a more advanced stage than electric taxis. The shift from gasoline to electric requires time, high investment, and test performances of this new transportation mode. Electric bus has been considered an important advance for public transportation system of Montevideo, significantly improving its quality service. Both projects are still under development.

In turn, walking is the most sustainable transportation solution that does not require any service and device. In Montevideo, several initiatives were developed to promote pedestrianism in different neighborhoods (Old City, Reus, and even in low-income peripheral suburbs), with the participation of the municipality and residents. The most relevant project in relation to pedestrianism was "Old city at human scale", which combines multiple activities related to the improvement of tourism service, environmental management, renovation of historic buildings, and the incorporation of bicycle lanes all around the historic center. Furthermore, the city of Montevideo has also proposed several measures to discourage the use of cars. However, more measures to discourage the use of cars could be applied to increase sustainable mobility solutions.

Finally, the characterization of urban accessibility is an important tool to determine the quality of transportation systems and their impact on the daily activities of citizens. In this line, two projects related to sustainable and universal accessibility and public transportation system have been analyzed: one for the city of Maldonado and the other for the city of Montevideo. For Maldonado, the objective was to characterize the accessibility provided by the public transportation system of the city to education centers, and for Montevideo the aim was developing a characterization of urban accessibility, as an important tool to determine the quality and equity of transportation systems and the impact on daily activities of citizens. Both projects arose useful inputs for the authorities, transportation companies, and academia, to identify situations of inequality in access to the different modes of transportation in the city.

In this line of work, this thesis proposes an analysis and characterization of sustainable initiatives developed for the public transportation of Montevideo, Uruguay. Table 4.1 summarizes main related works related to sustainable mobility and the TOD approach.

**Table 4.1:** Summary of related works about sustainable mobility and TOD

| *author(s)* | *year* | *main contribution* |
|---|---|---|
| Litman and Burwell | 2006 | Relationships between sustainable transportation and mobility |
| Litman | 1999 | Paradigm shift, rethinking transportation considering sustainable transportation solutions |
| Banister | 2008 | Emphasis the importance of the participation of stakeholders in the implementation of sustainable urban mobility plan. Seven key elements of sustainable mobility are outlined |
| Rodrigues et al. | 2008 | Studied methodological analysis and indicators for the evaluation of sustainable mobility in cities |
| Gudmundson et al. | 2016 | Indicators and frameworks for measuring sustainable development in the transportation sector |
| Jonhston | 2008 | Developed a comprehensive method of modeling impacts of transportation |
| Maclaren | 1999 | Combination of multiple indicators capturing different dimensions and aspects of sustainable mobility. |
| Miller et al. | 2016 | The role of public transportation regarding sustainable mobility |
| Rodrigues et al. | 2010 | Index of sustainable mobility |
| Baidan | 2016 | An example of the main problems of public transportation in Bucharest, Romania analyzed through accessibility indicators |
| Lyons | 2017 | Sustainable mobility strategy developed in Bogota, Colombia, based on three pillars and without automobile centric approach |
| Burchell et al. | 2000 | Introduce the concept of smart growth and new urbanist approach |
| Sung and Oh | 2011 | Regression models for transit ridership in rail station areas in Seoul to identify effects of TOD planning |
| Hasibuan et al. | 2014 | Analysis of sustainable development indicators and the applicability of TOD ideas for improving urban mobility in a case study in Jabodetabek |
| Loo and Du Verle | 2016 | Sustainable mobility approach oriented on people and places |
| Tsigdinos et al. | 2019 | Spatial analysis and definition of quantitative indicators for categorizing TOD regions with multicriteria analysis and geovisualization of the results |
| Woo | 2021 | Evaluation of different characteristics related to TOD paradigm in Seoul, Korea, to characterize different TOD types of subway station areas and their neighborhoods |

| *author(s)* | *year* | *main contribution* |
|---|---|---|
| Cervero and Dai | 2014 | Opportunities and challenges of leveraging TOD through BRT investments |
| Moscoso et al. | 2019 | Assessment and recommendations for mobility policies in Latin America |
| Bocarejo et al. | 2013 | Impact of Transmilenio on density, land use, and land value in Bogotá using a differences-in-differences methodology |
| Rodriguez et al. | 2016 | Development impacts around BRT stops in Bogotá and Quito |
| Alba et al. | 2020 | Analysis of sustainable transportation considering TOD indicators for universities in the Guadalajara metropolitan area, Mexico |

In addition, an empirical analysis of sustainable mobility under the Transit Oriented Development paradigm is proposed for Parque Rodó neighborhood, focused on properly capturing the relationships between urban environment, activities, and mobility, by analyzing diverse indicators. Specific recommendations are provided to improve sustainable mobility in the area of Parque Rodó neighborhood, based on a survey performed to people that commute to/from the area. The main contributions of this thesis are: i) a review of the related literature about sustainable mobility, the TOD approach, and projects developed in Uruguay in the matter of sustainable mobility; ii) the analysis of current initiatives of sustainable mobility in the public transportation system of Montevideo regarding several quantitative and qualitative indicators; iii) the analysis of the current situation regarding transportation and sustainable mobility in Parque Rodó neighborhood and Engineering Faculty; iv) the evaluation of the surrounding area of Engineering Faculty using TOD indicators; iv) the proposal of suggestions and recommendations to develop and improve sustainable mobility in Montevideo; and v) suggestions and recommendations to improve sustainable mobility in Parque Rodó neighborhood, applying the TOD paradigm.

# Chapter 5

# Sustainable mobility in the public transportation of Montevideo, Uruguay

This chapter presents the analysis of sustainable mobility initiatives recently developed in the public transportation of Montevideo, Uruguay. The contents on this chapter were published in the article 'Sustainable Mobility in the Public Transportation of Montevideo, Uruguay', Smart Cities, ICSC-CITIES 2019, Second Ibero-American Congress, Revised Selected Papers, Series Communications in Computer and Information Science, Springer (Hipogrosso, 2019) and later expanded in the journal publication 'Analysis of Sustainable Public Transportation and Mobility Recommendations for Montevideo and Parque Rodó Neighborhood', Smart Cities, 3(2), 479-510, 2020.

## 5.1 Introduction

Mobility is a crucial component of modern society, where the participation of citizens in social, economic, and cultural activities requires traveling over both short and long distances (Harvey, 1992). Sometimes, traveling takes citizens a long period of time, regardless of the distance traveled, due to many reasons related to mobility situations. The ability of individuals to overcome limitations imposed by time, distance, and other mobility-related difficulties is critical to guarantee an active participation in city life (Cardozo and Rey, 2007).

Sustainable mobility is a subject that studies the development and use of transportation modes that are sustainable regarding several matters, mostly economic, environmental, and social (Jeon, 2005). Assessing sustainability and studying alternative transportation modes is very important considering that transportation largely contributes to environmental pollution with direct negative implications in health and quality of life of citizens. This is a relevant subject of study under the novel paradigm of smart cities (Barrionuevo et al., 2012).

Modern urban areas have been built around automobiles. This transportation mode has dominated the urban landscape, gaining the majority of the space on streets, limiting pedestrians zones, and reducing the space for other (sustainable) transportation modes. Private vehicles have revolutionized mobility, but they have also introduced several problems, including pollution, environmental degradation, congestion, accidents, a decline in public transportation, lack of accessibility, etc. However, nowadays many cities across the world are designing sustainable mobility plans to limit the use of private cars by improving public transportation, encouraging sustainable transportation modes, creating pedestrian zones, and changing the negative transformation caused by automobile dominance. While acknowledging the importance of car mobility in modern cities, this article focuses on analyzing sustainable transportation initiatives as an important mean of promoting the shift from cars to more sustainable transportation modes.

One of the most sustainable modes for mobility is provided by public transportation systems (Miller et al., 2016). Public transportation allows moving a significantly larger number of people than private transportation, using a fewer number of vehicles. Furthermore, public transportation contributes to reduce greenhouse gas emissions, significantly improving the pollutant per passenger/km when compared with private vehicles. In the specific case of Montevideo, Uruguay, just a few initiatives have been recently proposed to promote sustainable private mobility (e.g., electric taxis and electric vans for last mile distribution of people and goods (MIEM, 2017)). On the other hand, several recent initiatives have been proposed for sustainable public transportation, which are under development.

In this line of work, this chapter studies sustainable mobility initiatives recently developed in Montevideo, Uruguay: electric bus, public bicycles, and electric scooters. The main motivation of the study is to analyze and characterize the current reality regarding sustainable public transportation in Montevideo, in order to make mobility more sustainable. Sustainable mobility alternatives are reviewed and categorized, and the main opinions about sustainable transportation modes are summarized and analyzed. Specific suggestions and recommendations are provided to develop and improve sustainable mobility in Montevideo.

The chapter is structured as follows. Section 5.2 presents the main concepts related to sustainable mobility. A brief description of current initiatives in Montevideo is reported in Section 5.3. The analysis of sustainable mobility in Montevideo is reported in Section 5.4. The suggestions and recommendations for developing and improving sustainable mobility in Montevideo are described in Section 5.4.4. Finally, Section 5.5 presents a summary of the main concepts and results presented in the chapter.

## 5.2 Sustainable mobility

Sustainability has been a major concern of modern society since the last decades of the twentieth century. Furthermore, sustainability has become a crucial aspect for nowadays communities, due to its direct implications on quality of human life and the growing awareness of the main issues and threats posed by environmental problems.

In 1987, the Brundtland Report for the World Commission on Environment and Development introduced the term sustainable development, to define "the development that meets the needs of the present without compromising the ability of future generations to meet their own needs" United Nations General Assembly (1987). Sustainable development has become a paramount rule for modern sustainable mobility, i.e., the process to guarantee the movement of people with minimal environmental impact. Indeed, the World Business Council for Sustainable Development defined sustainable mobility as the ability of a society to fulfill requirements related to the movement of people without sacrificing fundamental human or ecological values (World Business Council for Sustainable Development, 2015). Sustainable development is studied through three interrelated areas: the social, environmental, and economic dimensions. In several documents from the United Nations, sustainable development is said to be achieved when the goals of social equity, viable economic, and environmental friendliness are met in a coordinated manner (United Nations General

Assembly, 2015). Transportation and mobility are keys for sustainable development. Sustainable transportation can improve economic growth as well as improve accessibility (a very relevant social issue). Sustainable and safe transportation achieves a better integration of the economy while respecting the environment. As a consequence, sustainable mobility solutions must be designed considering these three areas, depicted in Figure 5.1, to contribute positively to their communities.


**Figure 5.1:** Main areas related to sustainable mobility.

The sustainable mobility paradigm integrates many relevant concepts (Banister, 2008). Among them, a new approach has been proposed for designing and planning transportation systems, based on social processes, accessibility, reduction of motorized transportation, integration of people and traffic, and other factors to consider mobility as a valued activity, regarding environmental and social concerns (Marshall, 2001).

Traditional research on sustainable mobility has focused on environmental impacts. However, several other important aspects have also been analyzed recently, including the relation with equity and the impact on economy, safety, health, and quality of life in general. In this regard, technology has been identified as one of the main tools that helps ensuring energy efficiency, using alternative and renewable energy sources, reducing contamination (e.g., pollutants emissions, noise, etc.), guaranteeing environmental friendliness, and providing tools for the analysis of reality and the development of new approaches based on data analysis. Furthermore, developing a rational plan for economic investments (e.g., infrastructure, transportation modes, etc.) is crucial to promote sustainable and solid growth in the long-term. Modern plans or courses of action are oriented to bring cities onto a more sustainable path with special emphasis on sustainable mobility, raising awareness, and involving citizens, with the main goal of fostering a behavioral change. The ultimate purpose is that citizens realize that transportation modes proposed by the sustainable mobility paradigm helps society, thus they opt for using more sustainable options by their own.

Several indicators have been proposed and developed to study sustainable mobility in urban scenarios (Gudmundsson et al., 2016). Among them, the most relevant are commuting travel time, coverage, access to mobility service, affordability, comfort and pleasure, intermodal connection, and integration. Indicators have been applied to analyze different transportation modes in many cities around the world. Some of the main related works on the topic are reviewed on next section.

## 5.3 Sustainable public transportation initiatives in Montevideo

This section describes and analyzes sustainable mobility initiatives that are operating in Montevideo through public or private transportation companies.

### 5.3.1 The public transportation system of Montevideo, Uruguay

Public transportation in Montevideo is mainly comprised of buses. Taxis and other minor systems also operates in the city. Regarding the bus system, city authorities proposed the Metropolitan Transportation System (Sistema de Transporte Metropolitano (STM)), an urban mobility plan with the main goal of restructuring and modernizing public transportation in Montevideo (Intendencia de Montevideo, 2008). Public transportation was integrated into a unified system comprised of 1528 buses operated by four private companies.

The bus network consists of 145 bus lines, but considering the different variants of each lines, the number increases to 1383, a remarkably large number for a city like Montevideo.

The city center is a hub in the bus network, with most lines converging to that area. Additionally, the large length of certain bus lines with respect to the area of Montevideo is also noteworthy: the average median bus line length is 16.4 km, with the longest line spreading over 39.6 km, also a large number, as the area of Montevideo is 530 $km^2$.

In 2019, taxis were integrated in STM. Passengers can pay the rides on any transportation modes using the STM smart card, contactless top-up cards that are linked to the identity of the owner. STM can also used to pay for rides in the public bicycle system, as described in the next section.

### 5.3.2 Sustainable mobility initiatives in Montevideo

Several sustainable mobility initiatives have been developed in the last years in Montevideo, Uruguay. Uruguay has assumed a strong commitment to environmental care and sustainable mobility moving forward to cleaner solutions. Electric mobility plays an important role in this change, particularly in the sector of public transportation and light vehicles (utilities and taxis). Electric mobility initiatives were explained in Section 4.3.4. Additionally, mobility on demand (MoD) surged as an innovative mobility services solutions in response to sustainable mobility. Electric scooter, pubic bicycle and car sharing are examples of MoD solutions that were explained in Subsection 4.3.3. Finally, some actions to promote sustainable mobility and discourage the use of private car were described in Subsection 4.3.5.

## 5.4 Analysis of sustainable mobility in Montevideo

This section reports the analysis of sustainable mobility in Montevideo through quantitative and qualitative indicators.

### 5.4.1 Indicators to assess sustainable mobility

The proposed analysis considers a subset of sustainable mobility indicators proposed by the World Business Council for Sustainable Development (2015). The analysis applies a mixed approach, considering quantitative and qualitative indicators, which is the dominant methodology for sustainable mobility analysis, according to the review by Anagnostopoulou et al. (2018). On the one hand, quantitative indicators are those for which the available data for the case study allows computing a numerical value to assess a sustainable mobility criteria. On the other hand, qualitative indicators are metrics based on opinions, feelings, or points of view, rather than specific facts or numbers. Qualitative analysis are applied when the relevant pieces of information are not available for the studied initiatives. In particular, for the case of study of Parque Rodó neighborhood, a survey based on specific interviews to a sample of 617 persons moving to/from the studied area was performed. Resulting data were analyzed both using quantitative and qualitative indicators.

#### 5.4.1.1 Quantitative Indicators

The quantitative indicator group includes coverage, access to mobility service, affordability, and commuting travel time. The corresponding definitions are presented next.

*Coverage*. The coverage is defined as the ratio of the area covered by each sustainable mobility service ($ci$) and the total urbanized area of the city ($ta$), according to Equation (5.1). The total urbanized area of Montevideo is considered to extend for 200 km$^2$. The scale for this indicator is straightforward, 0 correspond to 0% of coverage and 10 correspond to 100% of coverage.

$$coverage = \frac{ci}{ta} \tag{5.1}$$

*Access to mobility service*. Access to mobility service ($am$) is defined as the share of population with appropriate access to each service, according to Equation (5.2), where $nh$ is the number of citizens living in the city, $PR(i)$ is the percentage of people living within 400 meters from a public transportation stop or from a possible renting point of a shared mobility system and $\overline{PR}$ is the mean value of $PR(i)$.

$$am = \frac{\sum_i PR(i)}{nh} = 1 - \frac{\overline{PR}}{nh} \quad (5.2)$$

The methodology for calculation implies determining the percentage of people living within the service areas by using spatial data analysis. The service area is limited by a distance of 400 meters of a sustainable mobility service, which is considered as the maximum distance that a person considers to walk to use a public transportation service Atash (1994). The scale for the *am* indicator is 0 represents 0% of the population in the city and 10 represents 100% of the population.

*Affordability of sustainable mobility transportation.* Affordability ($af$) is defined as the expenditure on transportation made by persons as a percentage of their income. The calculation is based on the methodology by Carruthers (2005), considering the cost of performing 45 and 60 trips on each transportation mode and on existing socioeconomic data. The indicator is computed for two different relevant social groups, considering the minimum income and the middle income per capita, according to values reported for 2019 by National Institute of Statistics, Uruguay (Instituto Nacional de Estadística, Uruguay, 2019). The calculation method is described by Equation (5.3), where $nt$ is the number of trips, $p$ is the cost of a single trip, and $is$ is the income per capita. The scale for the $af$ indicator is 0 indicates affordability index is over 35% and 10 indicates that is less than 3.5%

$$af = \frac{nt \times p}{is} \quad (5.3)$$

*Commuting travel time.* This indicator is defined as the average time spent by a person when travelling from origin to destination of a trip performed in the public transportation system. The methodology applied for calculation considers that (i) (for bus) the average commuting travel time includes the time for a person to walk to the bus stop and the time waiting for the bus to arrive; persons are supposed to walk from the centroid of the zone and the average walking speed is assumed to be 5 km/h; (ii) (for bicycles) the average speed is 13.5 km/h and the average walking time to a bicycle station is 4 minutes (walking up to 400 meters); and (iii) (for scooters) the average speed is 12 km/h and the walking time a person takes to find a scooter is less than 3 minutes.

Commuting travel times are computed for two relevant distances: (i) a short travel of 3 km, a reasonable distance for travels to nearby locations such as offices, shopping, education, etc. It is also the average travel distance for electric scooters, considering an average speed of 12 km/h. (ii) A medium distance of 10 km, a reasonable average distance for travels to work, according to data from the urban mobility survey for Montevideo (Mauttone and Hernández, 2017). It is also the average travel distance on public transportation, considering an average bus speed of 13 km/h (Nesmachnow et al., 2017).

Two scales are considered for this indicator, for 3 and 10 km. Both consider as lower limit the time to travel the corresponding distance at the average human walking speed of 5 km/h, and as upper limit the time to travel the corresponding distance at the limit speed of bicycles and electric scooters (25 km/h). Thus, for the 3 km distance, 0 represent a trip duration of over 36 min and 10 represents a trip duration of 7 min, and for the 10 km distance, 0 represent a trip duration of over 2 h and 10 represents a trip duration of 24 min.

#### 5.4.1.2 Qualitative Indicators

The qualitative indicator group includes net public finance, energy efficiency, intermodal connectivity, intermodal integration, and comfort and pleasure. The corresponding definitions are presented next.

*Net public finance*: Percentage of the cost of each mobility service that the government grants as subsidy to transportation companies.

*Energy efficiency*: Energy consumption in public transportation, usually evaluated in oil equivalent. The efficiency indicator considers the total energy demand from clean (i.e., renewable) and non-renewable sources.

*Intermodal connectivity*: Number of locations where users can change from one transportation mode to another.

*Intermodal integration*: Quality of the intermodal facilities between the different transport modes.

*Comfort and pleasure*: Satisfaction perceived by citizens about comfort and pleasure of moving in the city using different transportation modes. Comfort and pleasure indicator is analyzed through access to information, quality of the service, and security.

### 5.4.2 Results of the analysis

This subsection reports the results of the study to characterize the sustainable mobility initiatives. The study applies a urban data analysis approach, which has been also applied by our research group to study public transportation and other services in Montevideo (Nesmachnow et al., 2017; Massobrio and Nesmachnow, 2020). The analysis accounts for relevant data about each initiative, obtained from open data sources (Open Data Catalog from the national government), data from previous studies (the urban mobility survey of Montevideo (Mauttone and Hernández, 2017)), and also from personal interviews with both technicians of the local administration of Montevideo and managers of the companies that operate the studied initiatives (CUTCSA and Grin).

#### 5.4.2.1 Quantitative Indicators

*Coverage.* The electric bus operated in several lines of CUTCSA company during 2017–2019. Table 5.1 summarizes the number of days of operation on the most relevant lines that operated the service. The percentage value for the number of days is also reported.

**Table 5.1:** Lines operated by the electric bus service in Montevideo (2017–2019).

| *Line* | *Days* | *Percentage* |
|---|---|---|
| 128 | 78 | 14.0% |
| 142 | 16 | 2.9% |
| 169 | 47 | 8.4% |
| 180 | 303 | 54.4% |
| 181/183 (circular line) | 45 | 8.1% |
| 187 | 20 | 3.6% |
| other lines | less than 6 days | less than 1% |

According to the results in Table 5.1, the area considered to calculate the coverage of the electric bus service is the one corresponding to the buffer area defined by parallel segments located at 400 m of the most used lines routes: 128, 169, 180, and 181/183. The distance of 400 m is defined based on the recent mobility survey for Montevideo (Mauttone and Hernández, 2017), which indicates that a person is willing to walk for up to about five minutes (corresponding to 400 m at a walking speed of 5 km/h) to access to a bus stop in order to use the public transportation service. In turn, for public bicycles, the coverage of the actual service and the projected coverage of the service are reported. The overall area for electric scooters is the one defined by the Grin service, which covers the area of service of the other two companies (Lime and Movo) that provided the service up to December 2019.

The area covered by each studied sustainable mobility initiative in Montevideo and the value of the *cov* indicator is reported in Table 5.2. Results were computed based on open data from each service.

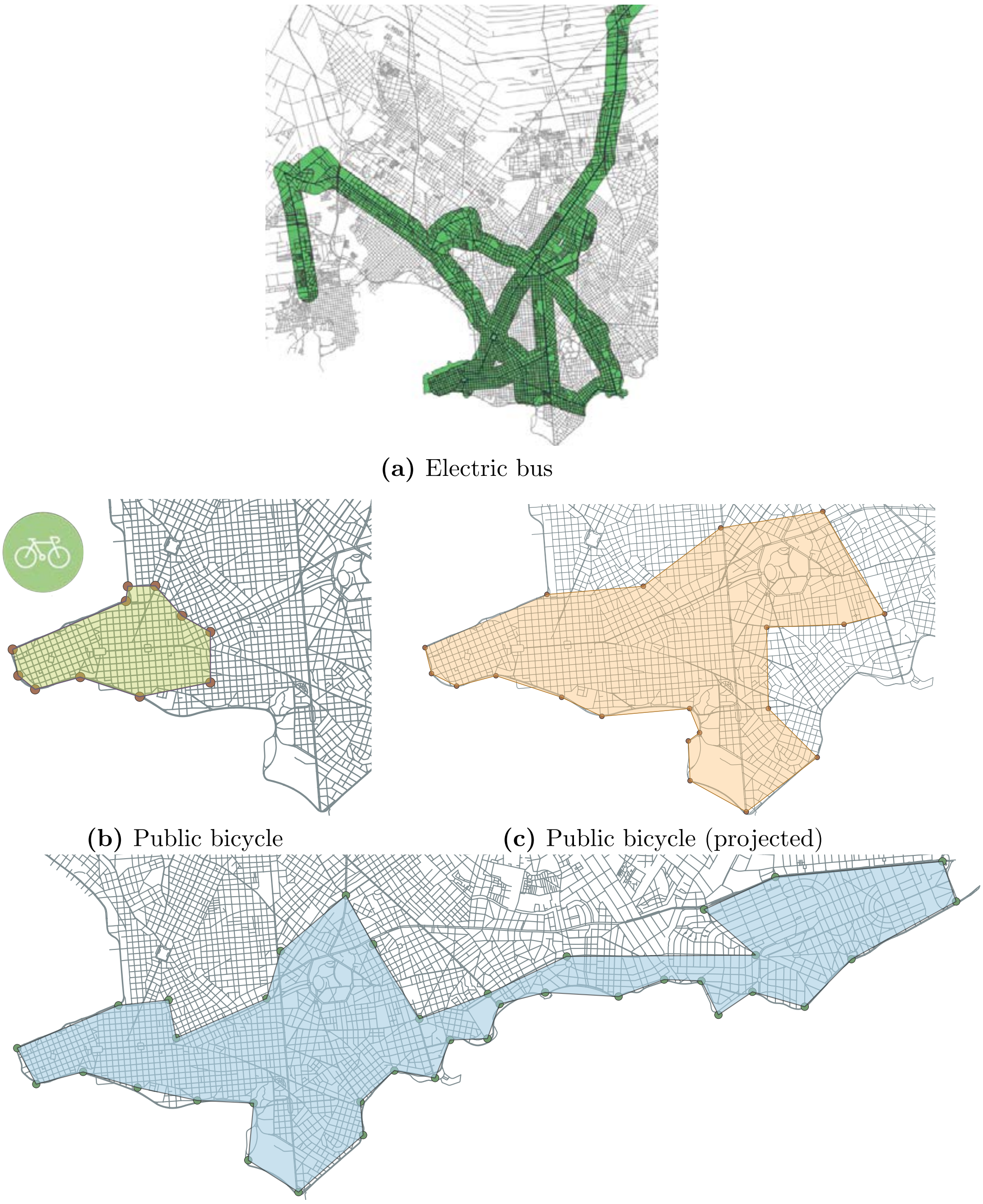
**Table 5.2:** Coverage and the *cov* indicator for sustainable mobility initiatives.

| *Initiative* | *Area* | *Coverage* | *Coverage index* |
|---|---|---|---|
| electric bus | 51.4 $km^2$ | 25.7% | 2.570 |
| public bicycle | 3.5 $km^2$ | 1.75% | 0.175 |
| public bicycle (projected) | 13 $km^2$ | 6.5% | 0.650 |
| electric scooter (Grin) | 23.5 $km^2$ | 11.75% | 1.175 |
| electric scooter (Lime) | 15 $km^2$ | 7.5% | 0.750 |
| electric scooter (Movo) | 7 $km^2$ | 3.5% | 0.350 |
| electric scooter (overall) | 23.5 $km^2$ | 11.75% | 1.175 |

The coverage maps for electric bus, public bicycles, and electric scooters services are presented in Figure 5.2. The analysis of the coverage indicator demonstrate that the area of service of each sustainable mobility initiatives is represents a small fraction of the total area of the city. The best coverage result was obtained for the electric bus service, which covers 25.7% of the city.

Coverage results are somehow expected, as the studied initiatives are new and public bicycles were introduced mainly for tourists. For electric scooters, coverage is also limited to zones with highest income (coastal area). Overall, the three studied modes provides a service that covers an area of 67.6 $km^2$, which represents 33.8% of the urbanized area of Montevideo, for a coverage index of 3.8. In conclusion, two-thirds of the the citizens who live in the urbanized area are not covered by these sustainable modes of transportation.

*Access to mobility service.* The population served by each service was computed by intersecting coverage areas with the population map and counting the total population in each zone. Figure 5.3 presents a superposition of the coverage area of sustainable mobility initiatives and the base map of population for Montevideo, grouped by census segments, which are used as the main administrative division for the Continuous Household Survey, from National Institute of Statistics, Uruguay (Instituto Nacional de Estadística, Uruguay, 2019). The urban population of Montevideo is 1,305,082.



**(a)** Electric bus

**(b)** Public bicycle

**(c)** Public bicycle (projected)

**(d)** Electric scooters

**Figure 5.2:** Coverage of sustainable mobility initiatives in Montevideo.

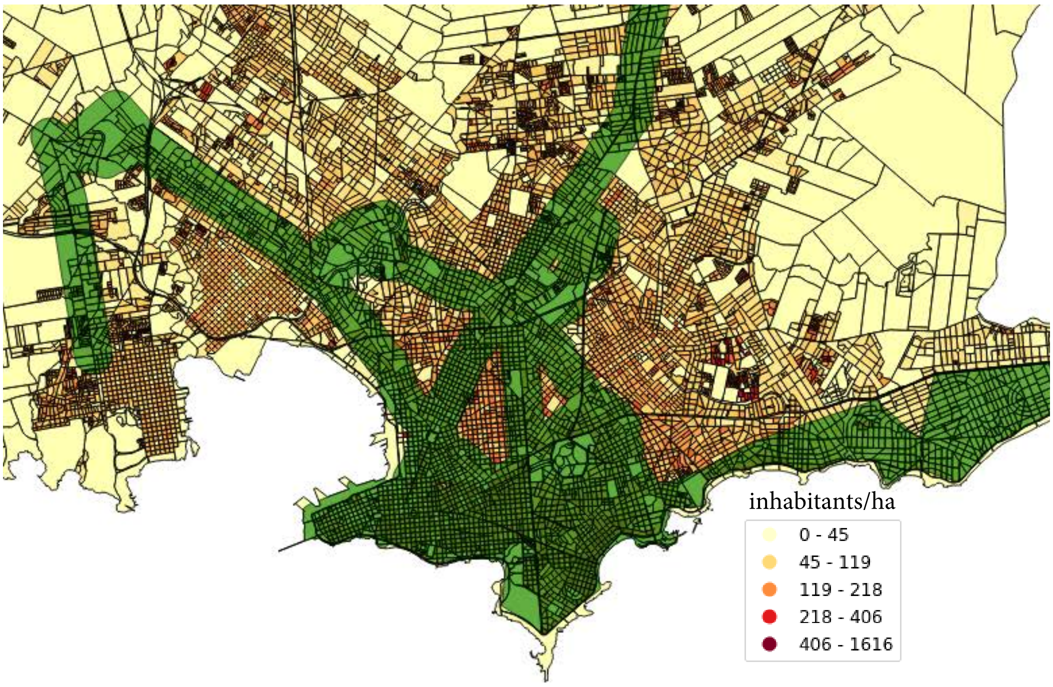



**Figure 5.3:** Coverage area of sustainable mobility initiatives and population of Montevideo (grouped by census segments).

The electric bus service covers 429,269 citizens (32.9% of the population), accounting for the largest access index ($am$ = 3.29). Public bicycles cover 86,917 citizens ($am$ = 0.67) and the planned expansion is set to cover 193,368 citizens ($am$ = 1.48). The electric scooters companies provides service to 285,445 citizens ($am$ = 2.19). Overall, sustainable transportation modes cover 554,172 citizens (42.5% of the population, $am$ = 4.25). As a consequence, the main conclusion from the analysis is that most of the urban population of Montevideo have no access to these sustainable modes of transportation.

*Affordability of sustainable mobility.* The affordability index was computed for the three studied transportation modes considering two types of trips: (i) short trips, with a length of 15 min, which is a reasonable traveling time for bicycles and and it is also the most frequent travel duration for scooters, according to the collected information, and (ii) long trips length of 45 min, which is the average time traveled in bus, according to the mobility survey (Mauttone and Hernández, 2017).

Income per capita in Montevideo is USD 691 (middle income) and USD 423 (minimum income), as from data from August, 2019, and considering 1 USD = 37 Uruguayan pesos. On the one hand, electric bus applies a flat rate.

The cost of a standard ticket, allowing one transfer trip in one hour, is 0.85 USD. On the other hand, electric scooters and public bicycles apply a time-based fare. The cost of using the public bicycles is 0 USD (free service) up to 30 min, and after that the rental cost is 0.74 USD for 30 min. For the electric scooter, the cost of a 15-min rent (the average time of utilization, as computed from the available data) is 2.1 USD and for one hour is 5.4 USD.

Table 5.3 reports the affordability index of each sustainable transportation mode for middle and minimum income people.

**Table 5.3:** Affordability (*af*) indicator for bus, bicycle, and scooter for minimum and middle income in Montevideo.

| *Trip Length: 15 min* | | | | | | |
|---|---|---|---|---|---|---|
| *income* | *45 trips* | | | *60 trips* | | |
| | *bus* | *bicycle* | *scooter* | *bus* | *bicycle* | *scooter* |
| minimum | 9.1% (8.2) | 0 (10.0) | 22.7% (3.9) | 12.0% (7.3) | 0 (10.0) | 30.2% (1.5) |
| middle | 5.5% (9.5) | 0 (10.0) | 13.9% (6.7) | 7.3% (8.8) | 0 (10.0) | 18.5% (5.2) |
| *Trip Length: 45 min* | | | | | | |
| *income* | *45 trips* | | | *60 trips* | | |
| | bus | bicycle | scooter | bus | bicycle | scooter |
| minimum | 9.1% (8.2) | 4% (9.8) | 57.2% (0.0) | 12.0% (7.3) | 5.4% (9.4) | 76.2% (0.0) |
| middle | 5.5% (9.5) | 2.5% (10.0) | 35.0% (0.0) | 7.3% (8.8) | 3.3% (10.0) | 46.7% (0.0) |

Results in Table 5.3 indicate that for 15 minutes trips, public bicycle has the maximum *af* value (10) for both income groups, as it is a free service up to 30 minutes. Affordability of bicycles does not reduce significantly when considering 45 minutes trips, due to the low fare of the service. Buses are cheaper than scooters for both short and long periods of time. Furthermore, the *af* indicator for buses is the same for both type of travels considered, while electric scooters downgrade to $af = 0.0$ for one hour trips. Overall, public bicycle is the most affordable transportation mode.

*Commuting travel time.* Table 5.4 reports the commuting travel times for three relevant distances for citizens' mobility in Montevideo: (i) 3 km, which is consider a short distance for those who primarily walk or ride a bicycle to work; (ii) 10 km, which is consider an average distance for bus commuters according to data from the urban mobility survey for Montevideo (Mauttone and Hernández, 2017) and in line with similar studies for similar cities in the world (Statistics Canada, 2020; Bureau of Transportation Statistics, 2017); and (iii) from end-to-end (*EtoE*) of the coverage areas for each mobility service. Speed and average times for bus were computed according to the methodology by Massobrio and Nesmachnow (Massobrio and Nesmachnow, 2020), using the Open Street Map service, estimations of average speed, and public applications available for the studied initiatives.

**Table 5.4:** Commuting travel times for bus, bicycle, and scooter in Montevideo (in minutes).

| *Bus* | | | *Bicycle* | | | *Electric Scooter* | | |
|---|---|---|---|---|---|---|---|---|
| 3 km | 10 km | EtoE (17.3 km) | 3 km | 10 km | EtoE (3.5 km) | 3 km | 10 km | EtoE (17.5 km) |
| 17.8 | 49.3 | 116.0 | 13.3 | 44.4 | 15.6 | 17.0 | 52.0 | 89.5 |

Results in Table 5.4 indicate that bicycle is the fastest option for both short (3 km) and long (10 km) distances, followed by the bus, and in third place the electric scooter. Differences between bicycle and bus reduce for trips of 10 km. EtoE bus trips takes longer than traveling on scooter, and almost the same time for shorter distances.

### 5.4.3 Qualitative Indicators

*Net public finance.* The electric bus initiative has received benefits from three subsidies in order to reduce the ticket price: a subsidy from the city administration to implement reduced fees for students and retirees, a fuel subsidy from the Ministry of Transportation, and other contributions from the Ministry of Economy and Finance. Furthermore, in 2019, bus transportation companies were granted a total of 100,000 USD each to promote the substitution of 4% of diesel buses to electric. The public bicycles service is completely financed by the city administration of Montevideo to promote active and sustainable mobility. Finally, electric scooters do not received any subsidy as they are run by private companies.

*Energy efficiency.* All the studied transportation modes use clean renewable energy. Public bicycle is the most efficient of the initiatives, as it does not requires energy of external sources. Electric buses provides a significant improvement over diesel vehicles regarding energy efficiency. They produce no $CO_2$ emissions and have an iron phosphate battery that consumes 100 KWh each 100 km, which is a good rate for public transportation. Regarding electric scooters, the energy of operation represents a very low percentage of the total emissions generated (e.g., 4.7% according to the study by Hollingsworth for the city of Raleigh, North Carolina (Hollingsworth et al., 2019). However, several other concerns arise, such as the non-clean energy required for collecting and distributing scooters, and the short life cycle of batteries, which can have negative environmental impacts. Even though the company introduced scooter stations to avoid picking up scooters one by one, users continue leaving scooters anywhere (the company did not apply any penalty fee for not using the stations).

*Intermodal connectivity.* The studied sustainable mobility initiatives operate in a common area of 2.8 $km^2$ (considering the projected expansion for the public bicycles system, the area increases to 7.3 $km^2$). Within this common area, public bicycles offer full connectivity with buses and scooters, as stations are located less than 100 meters of bus stops and scooters are available nearby. Electric scooters facilitate door-to-door mobility, allowing users to leave scooters in specific stations or even anywhere within the operation area, thus providing a valid alternative for intermodal connectivity. Buses also allows intermodal connectivity, but it is limited to a few bus stops that have bicycles or scooters stations nearby.

*Intermodal integration.* Even though the three transportation modes studied provide intermodal connectivity, the system as a whole lacks of intermodal integration. Each service focuses on their own operation, without facilitating integration with others: no information or route guidance is provided to users, terminal bus stations do not provide parking lots for public bicycles or scooters, etc. The only effective integration is regarding the payment method for buses and public bicycles, which can be paid using the same public transportation card (STM). All these facts are specific drawbacks for intermodal mobility. Overall, integration should be improved to provide efficient mobility.

*Comfort and pleasure.* Available information of public buses (e.g., via mobile applications) is recognized as one of the best features offered to citizens, according to the recent mobility survey for Montevideo (Mauttone and Hernández, 2017). On the other hand, trip comfort (43.9%) and bus stop comfort (46.4%) are the worst rated attributes of the bus system.

Users have presented claims about the poor service of Movete and bad conditions of bicycles (El País, 2019). Furthermore, Montevideo lacks of a proper infrastructure (e.g., exclusive bicycle lanes) for connecting stations of the system. Although the city administration planned to expand the network of bicycle lanes, even in the expanded configuration they will be not enough to properly satisfy the needs of an increasing number of users. In addition, it is difficult to complete even small infrastructure modifications, such as the case of the bicycle lane in Parque Rodó neighborhood, which is commented in Section 6.

Finally, users perceive many benefits of electric scooters: they are easy to locate, ride effortlessly, dock-less, and can be parked anywhere. On the other hand, electric scooters are vulnerable to road risks, as they are driven on the same lane as automobiles, and are an uncomfortable transportation mode for bad weather conditions.

### 5.4.4 General recommendations for sustainable mobility initiatives in Montevideo

This subsection provides some recommendations and suggestions that can be implemented in the city of Montevideo to promote sustainable mobility. Recommendations and suggestions are based on the review, analysis, and main results of the study of the three initiatives for public sustainable mobility, reported in the previous subsection.

One of the main facts observed from the analysis is that the initiatives for sustainable mobility are not widespread through the city. Instead, they provide a limited coverage and poor access to citizens. In this regard, one of the main recommendation is related to expand the coverage area, by introducing more bicycle stations, operating new lines of the electric bus, covering different routes or extending the routes offered, and expand the areas available to operate electric scooters. To improve coverage, more vehicles must be introduced and an articulated network of exclusive lanes has to be designed and implemented, which will help to improve other indicators too.

Specific suggestions to increase accessibility are extending the bus and bicycle networks, and the electric scooters operation. The expansion requires a proper previous evaluation of the real demand for each transportation mode, via direct (surveys) and indirect (mobility data analysis) methods. Another suggestion to increase accessibility is to perform a viability study of offering the studied mobility services to medium and low-income areas, thus increasing the social impact of the initiatives. The proposed suggestions are in line with strategies for sustainable mobility by bus reviewed by Fernandez and Fernandez (2018), and with the development of similar initiatives in Latin America.

Concerning affordability, the study demonstrated that electric bus is expensive and electric scooters are prohibitive for low-income citizens. This is a critical issue, mostly considering the periodic fare increases for those services at least once a year. In this regard, a specific suggestion for mobility services is to provide ticket packages for frequent users, and offering a lower price for combinations with other services, to facilitate inter-modality. Public finance support can be reviewed to better contribute to affordability, mainly by redirecting the assistance to reduce operation and maintenance costs, to guarantee a lower price for each service.

Other suggestions are related to improve travel time, in order to provide more useful and efficient sustainable transportation systems. In this regard, both city administration and transportation companies must focus on providing accurate information to citizens and guaranteeing a quick access to relevant information for travel planning. Electric bus should provide a higher frequency service, by redesigning or updating existing timetables, and a better effort must be done in order to provide good synchronization between different bus lines. For public bicycles and electric scooters, travel times are related to the availability of vehicles and also on the available interconnection network, so specific improvements on the fleets size and on infrastructure can contribute in this regard. To take advantage of the modal shift from diesel to electric buses to improve energy efficiency, smart planning of battery charge is needed, by properly locating charge stations in strategic points of the operation area or planning the use of external batteries. Electric scooters also need to review their operation efforts for collecting and distributing vehicles, which currently demands non-clean energy. A specific suggestion to improve efficiency is installing secure parking stations to charge scooters batteries while parked.

A clear recommendation to enhance sustainable mobility is to promote intermodal connectivity between transportation modes. In this regard, services should work on providing real-time data information (e.g., vehicles available, location, bus stops information, timetabling, etc.) and on installing shared stations for at least two of the studied services. A specific suggestion is to integrate the ticketing system, allowing users to share modes within a ride, maybe linked with the aforementioned offers to improve affordability.

In terms of comfort and pleasure, companies can offer a better quality service by improving the comfort of the vehicles, and particularly adopting security measures to guarantee safe travels. Bicycles and electric scooters can incorporate helmets to their service and buses can include seat belts for passengers. Related to the overall quality of experience, companies and city administration can improve access to information providing users with mobile applications oriented to reduce walking time, waiting time, and the overall travel times.

Other mobility suggestions regarding relevant features such as age, gender, socioeconomic situation, etc. can be performed when proper data is available, in order to extend the overall analysis in the mobility survey (Mauttone and Hernández, 2017). We are working to get that information from the city administration (Intendencia de Montevideo) under current project "Spatial, universal, and sustainable accessibility: characterizing the multimodal transport system of Montevideo, Uruguay".

In general, the economic viability of the proposed suggestions is feasible within the current business models of the companies that operate each service. Furthermore, most of the suggestions are in line with current developments by national institutions (city administration, Ministry of Industry and Energy), which have committed funds for promoting and developing sustainable transportation and sustainable mobility in the city.

## 5.5 Summary

This chapter studied three recent sustainable mobility initiatives implemented in Montevideo, Uruguay. The study analyzed the main concepts of sustainable mobility by a review of related work on the topic and applied the existing knowledge to analyze three sustainable transportation modes currently available in Montevideo (electric bus, public bicycles, and electric scooters) through quantitative and qualitative indicators of sustainable mobility.

Results of the study confirmed that the coverage area of the studied sustainable mobility initiatives is a small fraction of the total area of the city, thus a significant part of the population of Montevideo cannot access to sustainable transportation modes.

Public bicycle is the most affordable mode of transportation, and electric bus is the second best option, mainly because these two services benefit from subsidies and support from public finances, thus they can keep a reasonable price for users. Electric scooters have prohibitive prices for low-income citizens. Public bicycle is also the fastest and the most ecological option for short and long distance travels. On the other hand, the quality of service of the public bicycle system, regarding comfort and pleasure, is the worst of the three studied transportation modes. Finally, although the three modes provides intermodal connectivity between them, there is a lack of intermodal integration between services.

Taking into account the result of the analysis, specific suggestions were provided in regard of the main drawbacks of current sustainable mobility initiatives in Montevideo.

# Chapter 6

# Sustainable mobility plan for Engineering Faculty and Parque Rodó neighborhood, Montevideo

This chapter presents a practical approach for analysis and implementation of a sustainable mobility plan. A specific case study is addressed, demonstrating the viability of analyzing and implementing a sustainable mobility plan for Engineering Faculty and Parque Rodó neighborhood, Montevideo.

The contents on this chapter were published in the journal article 'Analysis of Sustainable Public Transportation and Mobility Recommendations for Montevideo and Parque Rodó Neighborhood', Smart Cities, 3(2), 479-510, 2020 and later expanded in the article (conference proceedings) 'Towards a Sustainable Mobility Plan for Engineering Faculty, Universidad de la República, Uruguay', Smart Cities, 2020, vol. 1359, 199-215, 2020.

## 6.1 Introduction

Smart mobility is a key factor for the modern paradigm of smart cities Deakin and Al Waer (2011). Mobility provides efficient means for social participation of citizens and also allows performing many of the daily activities on urban areas (Neckermann, 2017). One of the main research lines related to smart strategies for mobility is sustainable mobility (Tolley, 2003).

Issues related to mobility have posed major challenges for city planners and authorities in the last twenty years. One of the main problems concerns the increase on the number of automobiles and other means of private non-sustainable transportation, which do not guarantee a rational utilization of resources or a correct preservation of the environment. In fact, the close relationship between mobility (and transportation in general) and sustainable development has been recognized as one of the main issues to achieve the 2030 Sustainable Development Goals (SDG), as defined by the United Nation, since mobility is part of the great environmental challenges existing nowadays.

Several SDG are related to sustainable mobility, including relevant issues as health and road safety (SDG #3), affordable and clean energy (SDG #7), economic growth (SDG #8), resilient infrastructure for sustainable cities (SDG #9), and also regarding access to transportation modes and expanded public transportation (SDG #11), and sustainable consumption and production (SDG #12). Thus, promoting sustainable mobility has been a major concern and one of the toughest environmental and social challenges for modern cities.

The main concepts of sustainable development have been applied to conceive new approaches and models to guarantee smart mobility with a reduced environmental impact, allowing developing initiatives nowadays, without compromising the ability of future developments. Sustainable mobility is defined as the ability to "meet the needs of society to move freely, gain access, communicate, trade and establish relationships without sacrificing other essential human or ecological values, today or in the future" (World Business Council for Sustainable Development, 2002). The three main pillars of sustainable development (environmental, social, and economic (Jeon, 2005)) also support the sustainable mobility paradigm. These pillars must be duly respected to develop positive contributions, implementing collaborative efforts jointly by the public and private sectors, adequately considering citizens and their participation.

Sustainable mobility also requires a mind-shift: one where citizens, administrators, and decision-makers move from carbon-intense modes of transport to more sustainable solutions, like electric vehicles, car sharing, the expansion of bicycle and pedestrian lanes, as well as an overall shift from road to rail freight. With the rapid urbanization and increase of the environmental awareness and concerns, urban development have resulted in an urgent need and opportunity to rethink how we built and manage our cities to create climate-safe cities and ensure a better quality of life to citizens. However, governments should endeavor to move beyond simply pledging to reduce carbon emission to a specific level by a certain year it is necessary to adopt a sustainable mobility plan that could be developed for the future of our communities. There is a urgent need for re-planning the correct type and mix of transport modes to provide people efficient transport solutions to get to their activities.

In Montevideo, Uruguay, few initiatives have been proposed towards sustainable mobility. Most of the recent steps were focused in the public transportation, as it was explained in Section 4.3.4, by introducing electric buses in the public transportation system. Additionally, a few initiatives to promote sustainable private mobility have been developed in the last years (e.g., a leasing plan to acquire electric vans for last mile distribution of people and goods, the sustainable institution plan proposed by MIEM (2017) and described in Section 4.3.2, the extension of bicycle lane network, etc). However, no concrete mobility plans have been conceived for specific zones of the city.

In this line of work, this chapter studies the mobility demands of a specific zone of Montevideo, namely the surroundings of Engineering Faculty in Parque Rodó neighborhood. Besides analyzing infrastructure and specific conditions of the transportation modes available in the zone, an empirical approach is followed to consider subjective opinions, based on personal questionnaires to people traveling from/to the area. The resulting data are processed and analyzed following a urban data approach, in order to extract useful information and elaborate specific suggestions towards a sustainable mobility plan in the studied zone.

The chapter is organized as follows. Section 6.2 presents the analysis of the current situation in the studied zone and the survey used for the data collection process. The analysis and implementation of a sustainable mobility plan for Engineering Faculty is reported in Section 6.3. Section 6.4 describes suggestions and recommendations for developing and improving sustainable mobility in Engineering Faculty. Finally, Section 6.5 presents a summary of the main concepts and results presented in the chapter.

## 6.2 Mobility analysis and survey

This section describes the studied area and the methodology for collecting and analyzing mobility data.

### 6.2.1 Engineering Faculty and Parque Rodó neighborhood

Engineering Faculty (Facultad de Ingeniería) is the school in charge of engineering and other technology-related studies within Universidad de la República, Uruguay. In 2020, the Engineering Faculty has 10,350 students, 915 professors, and 195 administrative employees (Universidad de la República, 2019). All these persons have specific mobility demands to access to the institution.

Engineering Faculty is located in Parque Rodó neighborhood (South of Montevideo). A map of the studied area is presented in Figure 6.1. The studied area covers 0.5 $km^2$ and includes three main avenues: Herrera y Reissig, where Engineering Faculty is located; Sarmiento; and Sosa. Nearby the Engineering Faculty is Aulario Massera, a large classroom building shared by Architecture, Economics, and Engineering faculties.

Engineering Faculty has two parking lots with parking capacity for about 140 vehicles. The building also has bicycle parking (open from 7:00 to 23:00 from Monday to Saturdays) with security monitoring and a parking capacity of 330 bicycles. The bicycle parking has restrooms with showers and lockers to promote students using their own bicycles for traveling. This facility is under current norms for bicycles parking in public institutions, according to the administration of Montevideo.

Engineering Faculty has been promoting sustainable mobility initiatives. On June 2004, a group of professors founded “Unibici”, a program to promote the use of bicycles between students. Moreover, Engineering faculty worked together with the city administration of Montevideo to create bike lanes in a circuit connecting faculties of Universidad de la República. However, the project has not been completed yet.

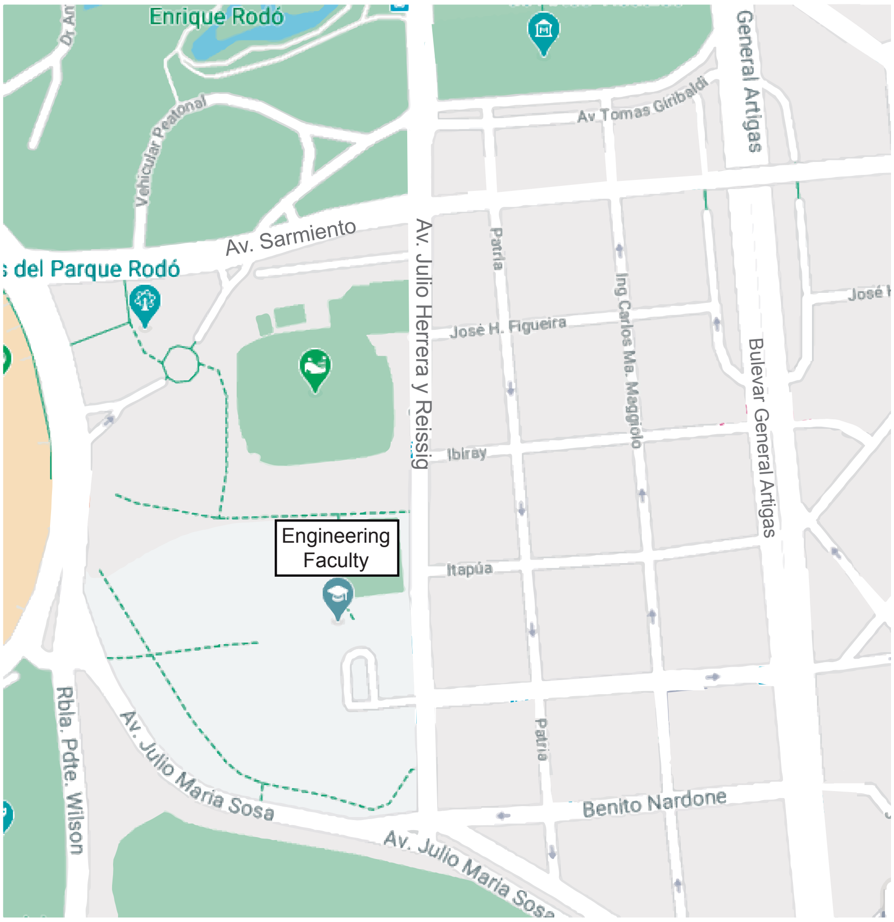



**Figure 6.1:** Area considered in the study: Engineering Faculty and Parque Rodó neighborhood.

### 6.2.2 Motivation and objectives of the study

The main motivation of the study is to understand the mobility demands to Engineering Faculty and Parque Rodó neighborhood, and also from Engineering Faculty surroundings to other zones of the city. The case study is relevant; it includes a variety of interesting features: Parque Rodó is a residential area, but also has a high education center (and others in the surrounding area), a shopping center nearby, several health centers in the zone, and other services. The study is based on data collected in-situ and the opinions of interviewed people are taken in consideration. The objective of the study is to identify, analyze, and characterize the current situation regarding mobility and sustainable mobility in the studied zone, for different groups of people.

The analysis of the current mobility situation provides quantitative and qualitative information for a systematic characterization of mobility demands in Engineering Faculty and Parque Rodó neighborhood. Moreover, the survey allows determining if the studied groups of people would be willing to change to more sustainable transportation modes and the specific issues that prevent them to make that change.

### 6.2.3 Methodology for collecting data

The methodology applied for gathering mobility information on the studied area consisted in collecting the information of the universe of study and performing a survey in situ.

Four relevant groups of people were identified: (i) students of Engineering Faculty and other faculties that shares Massera classroom building, (ii) professors and employees of Engineering Faculty, (iii) people who live in the neighborhood, and (iv) people who work on the neighborhood. By considering not only people from Engineering Faculty, but also from the surrounding neighborhood, the survey intends to capture a more holistic view, taking into consideration the different groups of people that travels to/from the studied area.

The total number of people involved in the analysis was 617(79 living in the area and 538 commuting from other zones of the city). Thus, the study considered a sample size of 2.15% for the analysis of the mobility situation of Parque Rodó neighborhood. The estimated size of the relevant universe is 28,602 persons, including people that live in the studied zone; students, professors, and employees of Engineering Faculty; and persons that commute to the area from other zones of the city. The sample size considered in the survey is significantly larger than the one used is similar initiatives. For example, the mobility survey for Montevideo (Mauttone and Hernández, 2017) studied 2230 homes, interviewing a total number of 5946 persons, which represent a sample size of 0.4% of the urban population of Montevideo.

The survey was formulated to know the mobility characteristics of the studied groups of people, it was totally anonymous and it included the following questions.

1. Do you study or work at Engineering Faculty?
2. Do you travel often to this area?
3. What is the origin and destination of your trip?

4. What transportation mode(s) do you use for commuting to study/work in the neighborhood or from this neighborhood to other zones of Montevideo?
5. If you use more than one transportation mode, specify the percentage of utilization.
6. How often do you make these travels weekly?
7. Which aspects are the most relevant for you while commuting?
8. Would you be willing to switch to a more sustainable transportation mode?
9. To what transportation mode would you be willing to change?
10. What do you think it prevents you to change to a more sustainable mobility ?

The survey was performed face-to-face to people circulating in the studied area. Interviews were performed in different locations, including the front door of Engineering Faculty, five bus stops located less than 300 m of the faculty, a bakery located 100 m from the faculty, the front door of Franzini football stadium, and also in random locations at streets in the zone: Julio Herrera y Reissig, Itapua, Ibiray, Patria, José Figueira, Eduardo Garcia de Zuñiga, Benito Nardone, Julio Maria Sosa, Carlos María Maggiolo, Sarmiento, Senda Nelson Landoni, and Bulevar Artigas. People were not interviewed at home, because the main interest was in specific mobility demands (e.g., people attending to Engineering Faculty, moving from/to work, or moving to shops in the area).

The questionnaires were performed during 15 November–15 December 2019, from Monday to Friday, from 8:00 AM to 7:00 PM. Weekend trips were not considered in the analysis because they are significantly lower than working days trips. Engineering Faculty offers just a few classes on weekends (just on Satuday morning, for some sporadic activities) and commercial activity in the studied zone is also reduced on weekends. People who commute in sustainable transportation modes were not asked if they would be willing to change towards a more sustainable transportation, as they already do it. The study also gathered information of bus lines that operates in the zone and identified the bus stops near the faculty. Scooter stations and bicycle lanes were also identified.

### 6.2.4 Methodology for data analysis

The study applies a urban data analysis approach, processing and analyzing relevant data from the survey performed in the studied zone and also information from public sources.

Regarding the methodology applied for data analysis, the study analyzes global characteristics of mobility demand in the area. Some indicators used for the global case of Montevideo are studied, e.g., coverage and commuting travel time, as defined in Chapter 5.4.1. In addition, other relevant aspects related to the sustainable mobility characterization are analyzed, such as travel distance and modal-choice preferences for trips. Travel distance is defined as the distance that a person travels from any point of the city to the centroid of the Parque Rodó neighborhood. All distances are computed using the Google Maps service. Modal-choice preference of commuters is defined as the decisions taken by individuals to chose one transportation mode instead of another. The reason for the choice is linked to several factors, including affordability, travel time, comfort, accessibility, and sustainability.

Furthermore, the study analyzes the quality of service of existing mobility options through mobility preferences while commuting, such as cost, comfort, speed, security, sustainability, and other valuable interests for citizens. The studied mobility preferences may not correspond to the transportation mode that people use today, but to modes that they are willing to use if those preferences and related issues improve.

Some indicators analyzed in the case study of Montevideo are not taken into account in the study of Parque Rodó and Engineering Faculty. For example, affordability or access to mobility service indicators are not computed, mainly because of two reasons: (i) from the point of view of the price of mobility services, prices are the same for all zones in Montevideo, thus the main results reported in Section 4.3.1 also holds for Parque Rodó and Engineering Faculty neighborhood, and (ii) most of the studied universe consists of middle/high income people, which normally can afford all transportation modes (this fact is confirmed by the low number of trips from/to those zones of the city with the lowest income per capita, which is below 8%).

## 6.3 Analysis of results

This subsection reports and discusses the most relevant results of the study. The most relevant results of the survey are presented on graphics, tables, and maps that allows characterizing distances, transportation modes, and other relevant features related to sustainable mobility in the studied zone.

*Coverage.* The studied area is fully covered by all the studied transportation modes (bus, bicycles, and electric scooters). Seven bus lines operates in the neighborhood, directly connecting people with many zones in the city. Furthermore, all locations in the city can be accessed via transfer trips. Although bus-only lanes were defined in main road and avenues of Montevideo, they are not defined in the studied area, so buses share the road with private transportation. However, just 47 trips of the electric bus (3.6% of the total trips performed in 2016–2019) operated in lines that serve Parque Rodó neighborhood. Regarding bicycles, the current public system does not cover the studied area, but it is projected to be covered in the expansion, as reported in the Section 4.3.1.

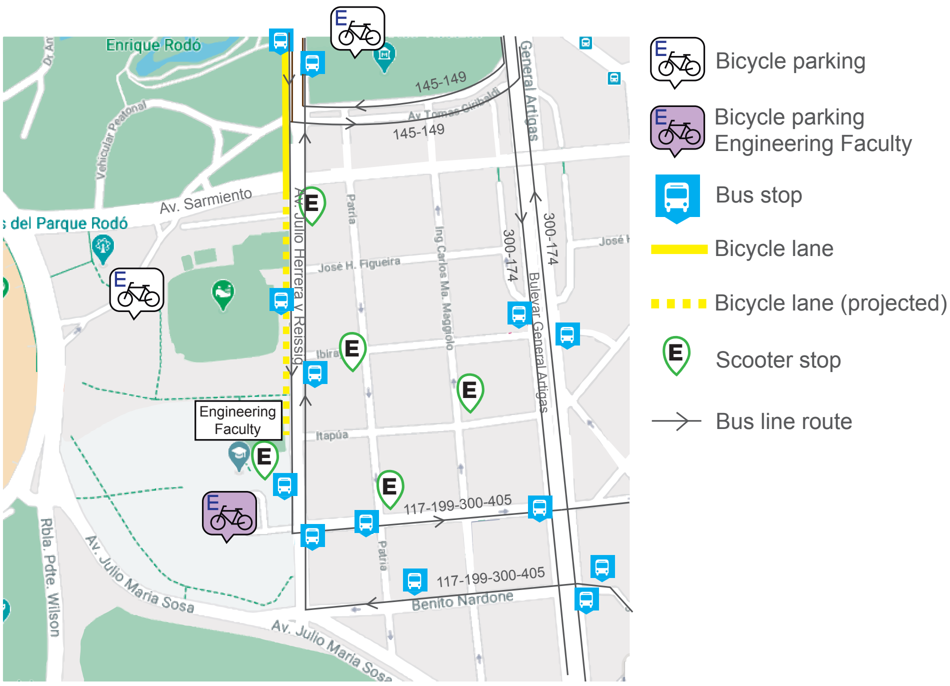



**Figure 6.2:** Coverage of Engineering Faculty and Parque Rodó neighborhood by the studied transportation modes.

Engineering Faculty provides the bicycle parking and other services for students, professors, and workers that use this transportation mode. Scooters operates all through the zone, having five stops near Engineering Faculty. Figure 6.2 present a coverage map of the studied zone, highlighting bus line routes and stops, scooter stops, bicycle parking areas, and bicycle lanes. The bicycle parking of Engineering Faculty is distinguished as it provides covered parking, security, and showers.

*Transportation modes.* Regarding the transportation modes used by people commuting to/from Parque Rodó and Engineering Faculty, Table 6.1 reports the number of trips using each transportation mode declared in the survey and the percentage that it represents over the total. Transportation modes are listed from more sustainable to less sustainable.

**Table 6.1:** Transportation modes used for commuting to/from Parque Rodó neighborhood and Engineering Faculty.

| *Transportation Mode* | *Number of Trips* | *Percentage* |
|---|---|---|
| walking | 83 | 13.0% |
| bicycle | 40 | 6.3% |
| scooter | 0 | 0.0% |
| bus | 361 | 56.4% |
| more than one transportation mode (on different days) | 69 | 10.8% |
| non-sustainable transportation modes (car, motorcycle) | 87 | 13.6% |
| total | 640 | 100.0% |

According to the results reported in Table 6.1, just 19.3% of the trips to/from Engineering Faculty and Parque Rodó neighborhood are done using sustainable transportation modes. Overall, more than half of the trips are done using the bus. The number of trips using other non-sustainable transportation mode is 13% (mainly private cars, just 1.4% on motorcycle), almost the same than people walking to/from the studied area. Bus is the most popular transportation mode, mainly because it is the most accessible and affordable transportation mode for large distances, as confirmed by the accessibility and affordability analysis of transportation modes for the city on Montevideo, reported in Section 5.4.2.

*Travel distances.* A summary of distances traveled by people from/to Parque Rodó and Engineering Faculty is reported in the pie chart in Figure 6.3. Travel distances were calculated in Google Maps considering the origin the Engineering Faculty and the destination the neighborhood people reported.

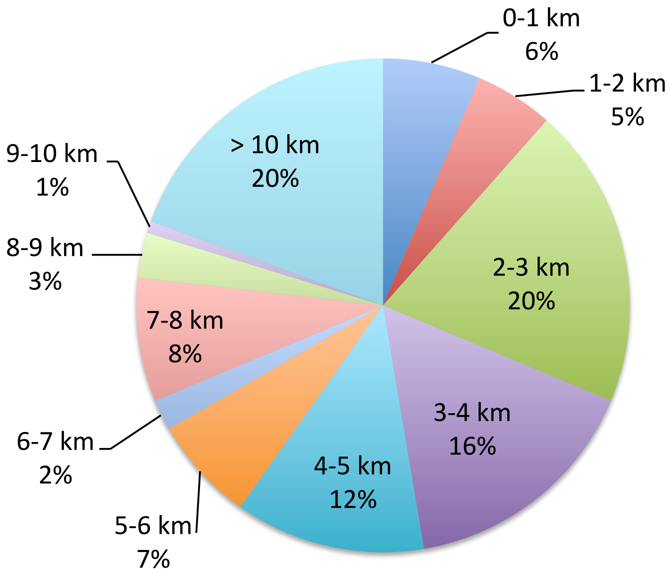



**Figure 6.3:** Travel distances according to data from the survey.

The analysis of travel distances indicates that 60% of the surveyed people commute from a maximum distance of 5 km away, and one-third of them travel between 2 to 3 km away. In addition, just 20% of the surveyed people commute a distance greater than 10 km. Furthermore, 95% of them declared to do a round trip, and 90% commute to the same place with a frequency of three times a week or more. These results confirms that the mobility demands in the studied zone follows a regular pattern, and that sporadic trips do not contribute significantly. Thus, the proposed approach, based on the analysis on frequent trips, provides a realistic characterization of mobility demands to/from Parque Rodó and Engineering Faculty.

*Transportation modes by distance.* Figure 6.4 refines the analysis of transportation modes, considering the average distance for each surveyed trip.

The analysis of data reported in Figure 6.4 allows concluding that walking is the most popular transportation mode for distances less than 2 km, followed by bicycle and bus. For distances between 2 and 5 km, bus is the most popular transportation mode, followed by walking and bicycle. For distances longer than 5 km, bus is still the most used transportation mode, followed by non-sustainable transportation modes: car and motorcycle.

Overall, the large number of people commuting to Parque Rodó and Engineering Faculty using non-sustainable transportation modes suggests that there is room to improve towards sustainable mobility in the studied area.

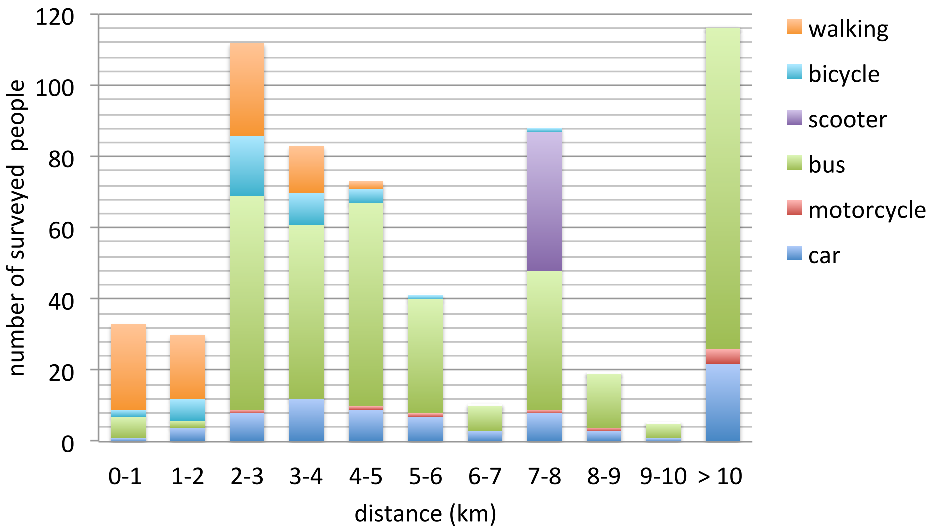



**Figure 6.4:** Transportation modes by distance.

Especially, 56.4% of trips using bus indicate that significant improvements to the service are definitely possible, by using electric buses. Specific actions can be also proposed to consider people traveling on car and motorcycles. This issue is studied in the following paragraphs, considering the information about preferences and motivations collected in the survey.

*Commuting travel time.* The combined analysis of distance and transportation modes allows computing the average commuting travel times for people commuting from/to the studied zone. In this regard, Table 6.2 reports the average travel times from/to the five most demanded origin/destination of surveyed trips, grouped by neighborhoods of Montevideo. The distance for each neighborhood is measured from Engineering Faculty to the centroid of each neighborhood.

**Table 6.2:** Commuting travel time to Engineering Faculty/Parque Rodó from the most frequent neighborhoods as origin/destination of trips.

| *Neighborhood* | *Distance* | *Bus* | *Bicycle* | *Scooter* | *Walking* |
|---|---|---|---|---|---|
| Parque Rodó | 1.0 km | - | 4.4 min | 7.0 min | 12.0 min |
| Cordón | 2.5 km | 18.9 min | 11.0 min | 14.5 min | 30.0 min |
| Tres Cruces | 3.0 km | 21.2 min | 13.3 min | 17.0 min | 36.0 min |
| Pocitos | 3.5 km | 28.4 min | 15.5 min | 19.5 min | 42.0 min |
| Centro | 3.7 km | 24.4 min | 16.4 min | 20.5 min | 44.4 min |
| Prado | 8.0 km | 44.4 min | 35.5 min | 42.0 min | - |

Results reported in Table 6.2 indicate that bicycle is the fastest transportation mode from distances shorter than 3 km. Scooter and bus are second and third regarding travel times, respectively. Considering that bicycles have no cost (either for using private vehicles or the public service projected for the zone) for up to 30 minutes, the bicycle is the fastest, most affordable, and most sustainable transportation mode for short distances. For distances between 3 km and 8 km, bicycle is the fastest transportation mode too, but a relevant issue that must be taken into account: when traveling long distances, commuters must consider that they might need to shower/change clothes due to the physical effort required, which would demand from a few to 10–15 additional minutes. Then, bus takes approximately the same time (i.e., 10 minutes more, but with no need to shower/change clothes) and scooter requires about four minutes more than bicycle, but considering that users can leave scooters in any place and there is no need to shower/change clothes, it is the fastest transportation mode. For distances larger than 8 km, all the studied transportation modes takes approximately the same time, so it is reasonable that most people use the bus, which is the most comfortable transportation mode, as reported in the previous analysis of transportation modes by distance.

*Aspects people prioritize while commuting.* Figure 6.5 summarizes the results of the analysis of those aspects identified as more relevant for people while commuting. The reported results are not necessarily linked to the transportation mode people use today, but to aspects they prioritize when commuting.

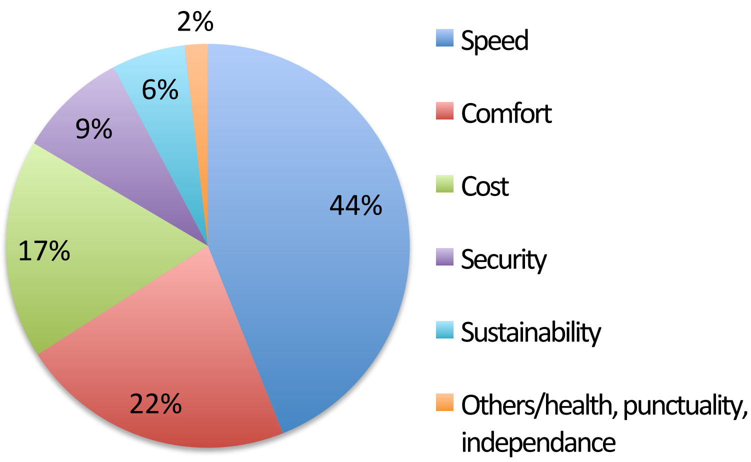



**Figure 6.5:** Aspects people prioritize while commuting.

The analysis of the aspects people prioritize while commuting indicates that 44% of the interviewed people prefer arriving faster to their destinations than other aspects. Comfort is the second feature more valued by the surveyed people (22%), and cost in third place (17%). Results obtained in the survey confirmed that aspects people prioritize do not depend on the distance or the travel time. In general, speed, comfort, and cost (in that order) are mentioned as priorities in declarations by surveyed people.

Overall, one conclusion can be formulated from the obtained results: public bus is the only transportation mode that could offer the three aspects people prioritize, in case it improves the actual service conditions. The other studied transportation modes cannot offer those three aspects, mainly because some of the are expensive (like private vehicles), ans several others require a physical effort and/or they are not comfortable in adverse climate conditions (like bicycle and scooter).

*Willingness to change towards more sustainable transportation modes.* The study interviewed 617 people, 504 of whom commute in non-sustainable transportation modes and 113 in sustainable transportation modes (bicycle or walking). Of those 504 people, 468 would be willing to change to sustainable transportation modes. This is a very relevant result, and is accounted as an empirical metric to determine the public acceptance of sustainable transportation modes within the people interviewed in our research. Furthermore, it is a first hint of the positive views towards sustainability, which can be confirmed by performing similar interviews in other (representative) neighborhoods of Montevideo. Figure 6.6 reports the results of the analysis of the sustainable transportation modes people would be willing to change.

According to the results reported in Figure 6.6, electric public transportation is the mode that most of the people would be willing to change (64%), followed by bicycle (32%). Considering that CUTCSA and other bus companies plan to develop the modal shift from diesel to electric buses after evaluating the results of the pilot plan explained in Section 5.3, the willingness to change can provide a big leap in sustainable mobility in the studied area. Taking into account the aforementioned results, the study analyzes next the reasons why people would like to change and why they do not actually change to both preferred transportation modes (electric bus and bicycle).

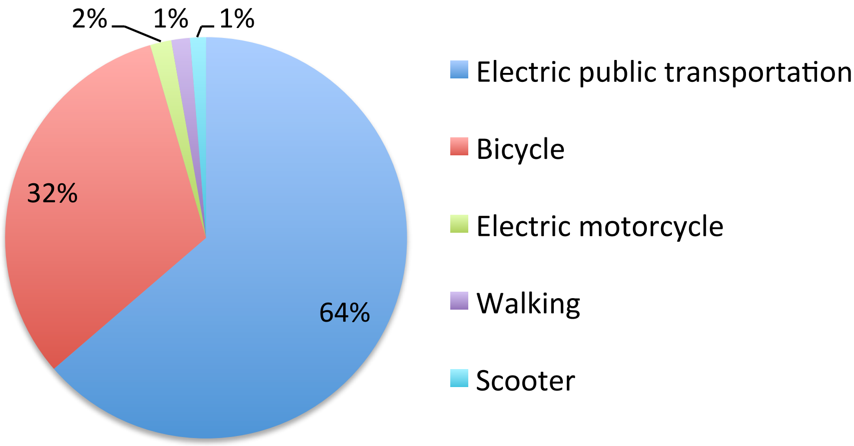



**Figure 6.6:** Sustainable transportation modes that people who commute in non-sustainable transportation mode might switch to

The reasons why people are willing to change to electric bus are mainly related to be part of initiatives oriented towards descarbonizing public transportation to reduce climate change and mitigate the environmental impacts of fossil fuels. Energy efficiency is also a motivation, especially considering that Uruguay is one of the leader countries in renewable energy in the world and it has a surplus of generated energy (over 98% of it generated from clean resources, according to reports for 2019 (International Energy Agency, 2019)). These opinions are in line with recognized benefits that electric public transportation provides to the communities they serve (improving air quality, reducing greenhouse gas emissions, financial benefits related to reduced maintenance and operating costs, and avoiding healthcare expenses) (Horrox and Casale, 2019).

Figure 6.7 summarizes some reasons why people might not change to electric public transportation. The analysis considers that no modifications on the current routes and frequencies will be associated to the electric bus, which will operate on the same conditions of the actual service (as suggested by the pilot plan implemented by CUTCSA).

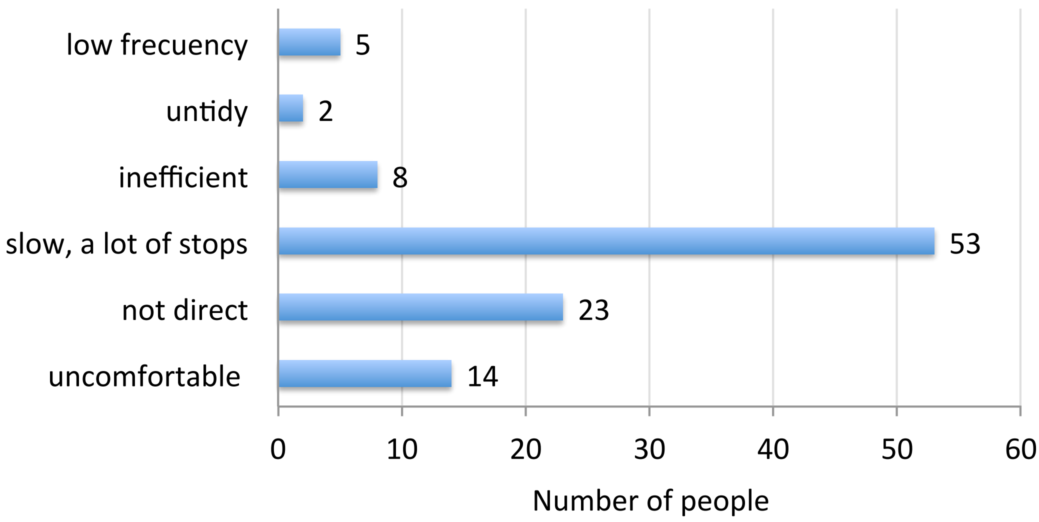



**Figure 6.7:** Reasons why people might not change to an electric public transport.

Regarding the results reported in Figure 6.7, the study collected opinions of 49 persons that travel in cars and would be willing to change to electric public transportation. However, most of them declared they will not change in case the bus will be inefficient, slow, untidy, with low frequency, and not direct. Additionally, 151 persons that travel today by bus would be willing to change to electric public transportation, even though most of them declared that they would also like to be faster, more comfortable, and more direct.

According to the survey, 149 of the interviewed persons reported that they would be willing to change to bicycle as transportation mode. In turn, 114 persons declared the reason why actually they do not use bicycle for commuting. The reasons why people are willing to do that modal change are related to the main benefits of riding a bicycle regarding health and also because it is the cheaper transportation mode, just as reported for the case of study of Montevideo.

Figure 6.8 summarizes the main reasons why people do not change their actual transportation mode to bicycle. Results correspond to 114 persons (eight traveling by car and 106 traveling by bus), who gave additional information about the reasons that prevent them to switch to bicycle.

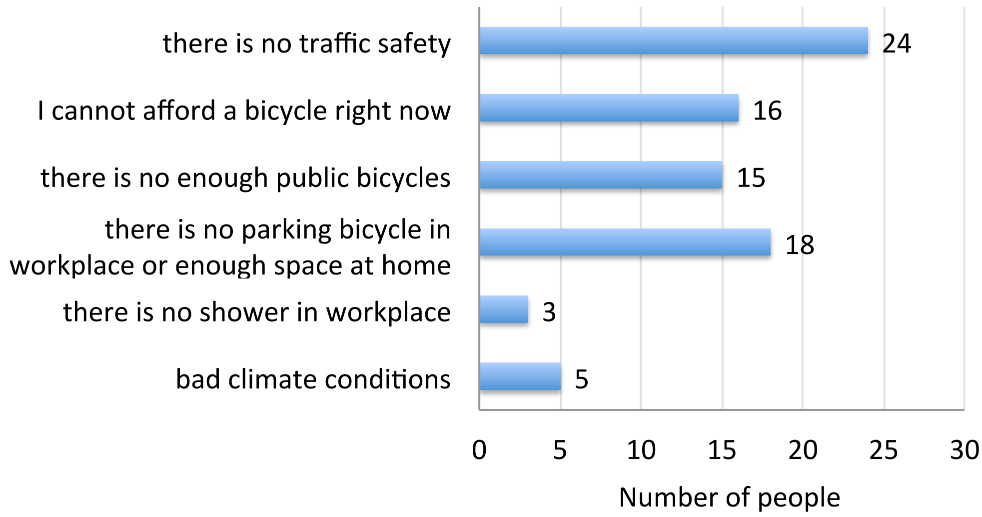



**Figure 6.8:** Reasons why people do not change to bicycle.

The information in Figure 6.8 state that car travelers mostly indicated the main reason is the reduced traffic safety, mainly because the few bike lines available in the city. In turn, bus travelers declared the main reasons for not using bicycle are the lack of proper facilities (e.g., their workplace does not offer a parking bicycle), they do not have enough space at home, and because they cannot afford a bicycle. Most actual bus travelers mentioned that they would use a public bicycle system if it was operating in the area.

## 6.4 General recommendations for sustainable mobility initiatives in Parque Rodó neighborhood and Engineering Faculty

This subsection provides specific suggestions and recommendations for improving sustainable mobility in the Engineering Faculty and Parque Rodó neighborhood. Recommendations and suggestions are based on the review, main results, and analysis of the mobility demands of the studied area especially considering the following concepts; the aspects related to accessibility (explored from the point of view of the infrastructures and services and and also from the point of view of people that commute from/to the studied area); the detected mobility patterns; and the motivation and opinions of interviewed people, which in fact constitutes a direct contribution of our research, as no previous similar studies have been developed in Montevideo.

One of the main facts from the analysis is that the studied area is fully covered by the studied transportation modes (bus, bicycle, and electric scooter). This fact makes it easy connecting people with other zones of the city directly or via transfer trips. However, in terms of sustainable mobility, the neighborhood is not covered by the public bicycle initiative and the electric public transportation of the pilot plan of CUTCSA developed during 2016–2019 only performed 3.6% of the total trips traveled through the studied area. In this regard, one of the main recommendations is related to expanding the coverage area of public bicycles, by introducing bicycle stations in this area and design an articulated network of exclusive lanes, which also will help to improve other indicators, besides coverage.

Regarding the used transportation modes, more than half of the trips from/to the studied area are made by bus. For distances longer than 2 km, bus is the most popular transportation mode. Furthermore, 64% of the interviewed people that travel using non-sustainable transportation modes would be willing to change to electric public transportation. In addition, results of the study confirmed that people will not change to electric public transportation if the conditions of the service remain as nowadays. This is an important result because the pilot plan implemented by CUTCSA was developed in identical conditions than the actual service, regarding routes, bus stops, travel times, and other relevant indicators. In this regard, several suggestions are related to improve public transportation, in order to provide more useful and efficient sustainable transportation systems.

According to the commuting travel time indicator, some people declared they are not willing to change their actual transportation mode for electric public transportation because buses are very slow, they have many stops, low frequency, and routes are not direct. Thus, some suggestions for the new electric public transportation relate to introducing lines with fewer stops and higher frequencies than the current service to allow commuters, especially those whose trips demand more than 50 minutes (10 km), arrive faster to destination.

In terms of comfort and pleasure, bus companies can offer a better quality of service by improving the comfort of vehicles. Some ideas to give users a better service include improving travel conditions (e.g., appropriate space, air-conditioning, and free WiFi), guaranteeing universal accessibility, providing accurate real-time information via mobile applications and digital screens in bus stops, reducing motor vibration and noise, among others.

Regarding infrastructure, in 2010 Montevideo incorporated bus-only lanes in main roads and avenues, to avoid traffic congestion and speed up public transportation. However, bus lines that circulate through the studied area still share the same lane with other transportation modes. In this regard, the studied area has few wide avenues to install bus-only lanes; e.g., Herrera y Reissig, which crosses Parque Rodó neighborhood, has only one line in each direction from Sarmiento to Sosa (end of the avenue), thus including a second (bus-only) line would require a major infrastructure modification. However, mobility can still benefit for installing bus-only lines in Bulevar Artigas or in Herrera y Reissig (north, where there is space available). Regarding infrastructure for bicycle, considering the surveyed responses, two relevant suggestions are formulated to foster the modal shift: (i) bicycle lines should be extended, at least to include the projected line that will reach Engineering Faculty (which is planned since 2013, and has not been constructed due to non-disclaimed reasons); (ii) in addition, companies located in the zone and also in the main destination neighborhoods should be encouraged to provide bicycles parking within workplaces and also restrooms with showers, to be used by employees after the physical effort required for a ride.

The reported results, descriptive statistics, and suggestions are very valuable for the city administration in order to conceive an effective sustainable mobility plan in the studied area.

Finally, we acknowledge the implications of the reported analysis on policies and decision-making related to two relevant research and development initiatives our research group is currently participating on: (i) local sustainable mobility plans, developed by Ministry of Industry, Energy, and Mining through the MOVES project, and (ii) project "Spatial, universal, and sustainable accessibility: characterizing the multimodal transport system of Montevideo, Uruguay", developed with the support of the local administration (Intendencia de Montevideo), with the main goal of creating valuable knowledge and formulate specific policies to develop and improve mobility and accessibility. Some specific examples that can benefit from the analysis reported in the previous subsection for Parque Rodo neighborhood are the redesign of bicycle lines in the zone and the planning of a route for the electric bus to provide mobility services to Engineering Faculty and other faculties in the district (Architecture Faculty and Economics Faculty).

## 6.5 Summary

This chapter studied the mobility analysis of Parque Rodó neighborhood and Engineering Faculty was based on a survey performed to 617 persons who commutes to/from the neighborhood from/to other zones of the city. This is an important contribution of the reported research, since no previous analysis of sustainable mobility has been performed for specific zones of Montevideo.

Results of the study indicate that the area is fully covered by all the studied transportation modes (bus, bicycle, and electric scooters). However, in terms of sustainable mobility, the neighborhood lacks of a proper coverage, as the public bicycle initiative does not operate in the area and electric public transportation only did 3.6% of the total trips in 2016–2019 through the studied area. The survey reported that more than half of the trips from/to the studied area are made by bus. Bus is also the most popular transportation mode for distances longer than 2 km. This is a relevant result, because, according to the survey, more than half of the persons that currently travels using non-sustainable transportation modes would be willing to change to electric bus. Thus, the modal shift to electric mobility on public transportation turn to be an important topic to address in the studied zone.

Despite the fact that the pilot plan for electric buses was successfully deployed and valued by citizens, and this transportation mode will provide users a better service and move towards sustainable mobility, people declared they are not willing to change their actual transportation mode if electric buses operate in the same conditions to the actual service. As a consequence, the shift from diesel to electric does not ensure the modal change to public sustainable transportation if buses still operate as in the actual service. To attract more users, bus companies should work on improving speed (one of the most important aspect people prioritize while commuting) by rethinking the routes and stops of new electric buses and also travel conditions in terms of comfort and pleasure (e.g., providing appropriate space, air-conditioning, free WiFi, etc.), which is another of the main aspects to solve to succeed in the modal change of citizens.

An important result of the mobility analysis in Parque Rodó and Engineering Faculty is that more than half of the surveyed trips involve distances shorter than 5 km, i.e., suitable distances to commute by bicycle. The study also reported that a quarter of the interviewed people are willing to switch to bicycle as a sustainable mobility alternative. However, the lack of infrastructure (bicycle lanes, bicycle parking and showers at workplace) discourages people to use the bicycle for commuting to/from the studied zone. Thus, improving the mobility conditions for bicycles turn to be an important topic to address in the studied zone.

Overall, the sustainable mobility situation and demands of Parque Rodó neighborhood and Engineering Faculty is a valuable tools for helping academics, transportation companies, and stakeholders to analyze and evaluate possible solutions to implement sustainable mobility plans. The reported case study in Parque Rodó provides a basis for building more powerful surveys and data collection activities to better understand sustainable mobility in the whole city.

# Chapter 7

# A practical approach for sustainable Transit Oriented Development in Montevideo, Uruguay

The need for a proper development of transportation systems in modern smart cities is motivated and driven by relevant factors, including conceiving territorial and transportation planning as part of an unified urban activity. In this line of work, this chapter presents an empirical analysis of sustainable mobility under the Transit Oriented Development paradigm. The proposed approach properly captures the relationships between urban environment, activities, and mobility, by analyzing diverse indicators. As a relevant case study, this chapter analyzes the current situation regarding sustainable mobility and Transit Oriented Development in the area surrounding Engineering Faculty, in Parque Rodó Neighborhood, Montevideo, Uruguay. Specific recommendations are provided to improve sustainable mobility under the studied paradigm.

The contents on this chapter were published in the article 'A practical approach for sustainable Transit Oriented Development in Montevideo, Uruguay', Smart Cities, Communications in Computer and Information Science vol. 1555, 256–270, 2022, Springer and extended in the journal article 'Transit Oriented Development analysis of Parque Rodo neighborhood, Montevideo, Uruguay' submitted to World Development Sustainability April 2022.

## 7.1 Introduction

Sustainable development has been recognized as one of the main issues to achieve the 2030 SDG. Several of the defined SDG are related to sustainable mobility, including relevant issues as health and road safety, affordable and clean energy, economic growth, resilient infrastructure for sustainable cities, access to transportation modes and expanded public transportation, and sustainable consumption and production. Thus, promoting sustainable mobility has been a major concern and one of the toughest environmental and social challenges.

In a broad sense, one of the main ideas behind the smart sustainable mobility concept is to reduce or even limit the use of private motorized vehicles. Citizens must be properly informed and encouraged to shift to more sustainable transportation modes, which must provide accessible, less expensive, and environmentally friendly mobility. In turn, Information and Communication Technologies provide support to smart mobility by collecting, processing, and communicating relevant information for both citizens and authorities. Citizens use the information for achieving faster, more secure, and reliable trips, whereas authorities are able to perform a better management of traffic, public transportation, pollution, and overall costs of multi-modal transportation system, via intelligent methods that support decision making.

In practice, authorities have many options to implement smart mobility solutions. One of the most robust approaches consists in re-thinking the urban design, by taking into account the mobility needs. In this regard, Transit-Oriented Development (TOD) (Calthorpe, 1993; Newman and Kenworthy, 1995) is a paradigm for urban planning and development that was proposed with the main goal of revitalizing city urbanization, by the combined application of two strategies: the renewal of suburban spaces and the design of friendly sustainable mobility environments in neighborhoods. The TOD paradigm has been successfully applied in the developed world, especially in USA, Europe, and Asia. In these locations, several key principles have been applied to guarantee the development of sustainable mobility means, also contributing to the economic development and improving the quality of life of citizens. However, few proposal related to the TOD paradigm have been proposed in Latin America, and few publications have analyzed the impact and success of the TOD methodology for developing sustainable transportation modes.

In this line of work, this study presents a practical approach for analyzing and developing sustainable mobility initiatives under the TOD paradigm. The methodology applied for the analysis focuses on properly capturing the relationships between urban environment, activities, and mobility. An urban data analysis approach (Massobrio and Nesmachnow, 2020) is proposed as the most reliable methodology for processing the available data, extract useful information, and compute relevant indicators for the study. The proposed approach is applied to evaluate a specific residential area in Parque Rodó neighborhood, Montevideo, Uruguay. Although TOD has become a popular approach for city planning, few articles have analyzed the impact and success of methodologies for developing proper sustainable transportation modes in Latinamerican cities, and this is the first study of its kind for Montevideo.

Several data sources are considered to gather relevant information for the reported study, including open data repositories, non-open data obtained by agreements with local authorities, in-situ interviews and personal inspection of the studied area. Several quantitative indicators are computed and applied to analyze the mobility demands and other relevant concepts related to sustainable mobility. In turn, well-known TOD indicators are also applied to characterize land uses, activities, and existing transportation modes, and also to review the opportunities and willingness of citizens traveling from/to the studied area to shift to sustainable transportation modes. Results of the study indicate that the studied area has appropriate values of relevant TOD-based indicators. The main conclusion of the analysis is that the studied zone has very good potential for developing sustainable mobility. Several suggestions and recommendations are formulated towards applying the TOD paradigm to improve sustainable mobility. The presented case study is valuable as a relevant example of a formal methodology that can be applied in other zones and other cities.

This chapter is organized as follows. Next section introduces the main concepts of the TOD approach and the TOD standard. The analysis of the study zone regarding TOD is reported in Section 7.3. Results and discussion of the analysis are presented in Section 7.4, and specific suggestions and recommendations to improve sustainable mobility under the TOD paradigm in the studied area are presented in Section 7.5. Finally, Section 7.6 presents the conclusions and the main lines for future work.

## 7.2 TOD approach

In the last thirty years, sustainability has been a major concern of modern society. The concept of sustainable development, i.e., fulfilling important roles of nowadays without compromising the future, has been promoted to build a more equitable, environment friendly, and inclusive model of society.

The sustainable mobility paradigm integrates many relevant concepts, including those related with their impacts on environment and society (Banister, 2008). Overall, the main idea is to consider mobility as a valued activity regarding environmental, social, and economic concerns (Marshall, 2001). One of the most studied aspects has been the impact of mobility on the environment, with the main idea of conceiving new transportation paradigms accounting for cleaner means, accessibility, and integration of people. Other important aspects have also been analyzed, including the impact on economy, and the overall quality of life (safety, health, etc.)

In turn, the TOD paradigm for urban planning is a trendy model for planning sustainable urban communities by creating dense, walkable communities that greatly reduce the need for driving and energy consumption. The goal TOD is ensuring sustainable mobility and economic development, while protecting global energy. TOD has become a great prominence for urban planning and transport since the first proposals by Calthorpe (1993) and Newman and Kenworthy (1995) in the 1990s. The approach was later supported by the empirical works of Bertolini (1996), Bertolini et al. (2012), Cervero (2007), and Cervero and Dai (2014), among other authors. TOD is the key to more sustainable, efficient, and equitable communities because it works under the "3Cs" concepts (compact, coordinated, and connected). In turn, it is related to other five principles for decision makers and urban planners strengthen their communities according to the TOD standard:

1. *Compactness*: The closer the activities are located between each other in a compact city/district, the less time consuming and energy is required.
2. *Density*: Instead of building out to increase the urban sprawl, TOD supports building up to create dense cities in a more compact way.

3. *Transit–public transportation*: Public transportation connects and integrates many distant areas around the city. A good public transportation planning that contemplate all area of a city creates an equitable and accessible city.
4. *Connectivity*: Create dense networks of streets and paths for pedestrians and cyclists as well as public transportation.
5. *Mix*: Plan for mix use in order to create shorter trips and more lively neighborhoods.
6. *Cycling*: Prioritize non-motorized transport networks. Cycling provides people an efficient and convenient way to travel for short/medium distances, increase accessibility as well as coverage of transit.
7. *Shift (to sustainable transportation modes)*: Closer locations between activities and a good transportation network do not imply people shift to sustainable transportation modes. Other actions are needed, such as regulating car parking and road use, to discourage the use of non-sustainable means.
8. *Walk*: Develop neighborhoods that promote walking creating vibrant, active streets where people feel safe.

In the related literature, TOD is conceived to hold urban sprawl, prioritizing sustainable mobility as well as driving to environmentally and economically-balanced growth. TOD is closely related to the *smart growth* and *new urbanist* approaches (Burchell et al., 2000) conceiving walkable, compact, pedestrian-oriented, and mixed-use communities centered around high quality public transport systems (Sung and Oh, 2011) reducing, in this way, the utilization of automobiles.

Several articles have defined a buffer of 400 m as the walkable distance to get to a bus stop and a buffer of 800 m as the walkable distance to get to a rail station (Papa and Bertolini, 2015; Renne, 2009). According to these radius, urban designers and planners design mixed used areas around bus stops and rail stations to promote sustainable mobility. Accessibility also plays an important role when designing a project based on TOD principles. The interaction between urban structure, accessibility, and travel behavior has been discussed for several authors (Papa and Bertolini, 2015).

## 7.3 TOD-based sustainable mobility analysis for Engineering Faculty, Montevideo, Uruguay

This section describes the analysis of sustainable mobility and urban structure in the area surrounding Engineering Faculty, Montevideo, Uruguay, considering TOD-related indicators.

### 7.3.1 Motivation and objectives of the study

The objective of this chapter is to analyze how the studied area can be transformed in a walkable, compact, pedestrian-oriented, and mixed-use community, where people want to live and work, built around sustainable public transportation.

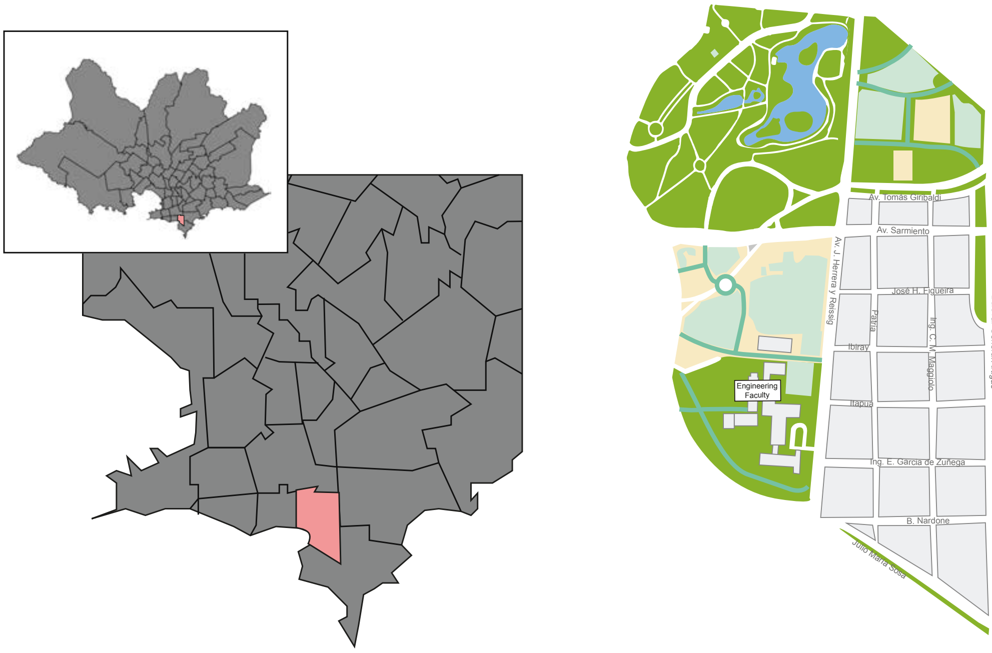
Since global concern of environmental pollution appeared, only few initiatives have been proposed towards sustainable mobility in Montevideo. Most of the recent initiatives focused on public transportation, e.g., electric buses were introduced in the system, and a few private initiatives, e.g., a leasing plan to acquire electric vans for last mile distribution of people and goods.

The studied area (called *The Isle*) is located nearby Engineering Faculty, in Montevideo. It is an area of 0.25 $\text{km}^2$ surrounded by about 1 $\text{km}^2$ of green areas (Parque Rodó/Rodó Park). Although The Isle is a residential area, where more than 5.000 people live, it has high daily flow of people traveling to/from services, institutions, green and recreation areas, and other places located in the zone. In this regard, this area creates opportunities for multi-modal travel, sustainable mobility and urban planning development based in TOD approach.

Figure 7.1 presents the location and details of the studied area in Montevideo, Uruguay.

### 7.3.2 Methodology

This subsection describes the methodology used for collecting data, indicators and metrics applied and the methodology of data analysis in the studied area.




(a) Location of the studied area (b) Details of the studied area

**Figure 7.1:** Details of the studied area in Montevideo, Uruguay

#### 7.3.2.1 Overall description

The study is based on two methodological stages: i) applying urban data analysis (Massobrio and Nesmachnow, 2020) to develop a spatial-functional definition of the study area; and ii) characterizing the current mobility in the studied area, via relevant quantitative indicators related to the user experience when commuting from/to the studied area. The proposed methodology combines different quantitative indicators, qualitative evaluations and analysis to identify land uses and mix in the studied area, the connectivity provided by existing transportation means, and the infrastructure for bikers, pedestrians, and users of public transportation, with the main goal of improving accessibility and developing sustainable mobility in the area.

#### 7.3.2.2 Data collection

Three main sources of data were considered in the study.

First, data were collected from Google Maps (downloaded in JSON format and processed using GIS software) and from personal inspection (using photographs taken in the studied area) to perform the spatial-functional analysis of the studied area.

Within the collected data, the following information about the environment is included:

1. infrastructure for non-motorized traveling mode (pedestrian-only paths, bicycle paths, accessible ramps for sidewalks);
2. land uses (commercial, residential, institutional);
3. the presence of semi-public spaces (restaurants, education center, health center, sport centers);
4. the presence of open spaces (green areas, parks and squares);
5. maintenance condition of the built environment and green spaces in the surveyed area (bus stop shelter, sidewalks, bicycle paths);
6. parking facilities and transportation nodes (bicycle parking, and bus stops).

According to TOD concepts, the analysis was performed in two areas: The Isle, which is located within 400 m of Engineering Faculty, and an extended area delimited by a radius of 800 m from Engineering Faculty (mostly in directions North and East). The radius of 800 m is considered to be an appropriate scale for pedestrians, according to research focused on the last mile problem for transportation of people and goods (Juhász and Bányai, 2018).

Second, operational data was gathered about public transportation (e.g., bus lines that operates in the zone, timetables, etc.) and also information about the available infrastructure (e.g., bus stops, bicycle lanes and bicycle parking facilities) was collected either from open data sources or by personal inspection.

Finally, the study reported the most relevant information for the mobility analysis survey of Parque Rodó neighborhood and Engineering Faculty described in Chapter 6. The survey focused on gathering mobility information for those different groups of people. The study includes the most relevant information for the analysis: origin/destination of trips and relevant aspects of transportation mode(s) used for commuting.

#### 7.3.2.3 Indicators/metrics

Several indicators were considered for the evaluation of the urban infrastructure in the studied area:

1. The existence of infrastructure for non-motorized transportation modes, including pedestrian paths and bicycle paths;
2. The total length of paths for non-motorized transportation modes;
3. The existence of infrastructure to provide universal accessibility on sidewalks and bus stops;
4. The number of shops in both the studied and the extended area.
5. The total area of commercial, residential, educational, recreation and green zones;
6. The number of bicycle parkings and bus shelters;
7. The maintenance condition of the built environment (bus shelters, sidewalks, bicycle paths, green areas), evaluated in three qualitative categories (low, medium, and high). In this regard, the analysis considers 'The 8 principles of sidewalks' (Dos Santos et al., 2019) as reference for design and construction of sidewalks and the National Association of City Transportation Officials (NACTO) Urban Bikeway Design Guide (National Association of City Transportation Officials, 2020) as reference for bicycle paths.

For the analysis of urban data to characterize the current reality of mobility in the studied area, three relevant (quantitative) sustainable mobility indicators proposed by the World Business Council for Sustainable Development were used:

1. Distance between origin and destination of trips, which accounts for the real distances that people travel, considering the specific zones that originate trips to the studied area and also the destination of trips that initiate in the studied area.
2. Commuting travel time, which is defined as the average time spent by a person when traveling from/to the studied area. The average walking speed is assumed to be 5 km/h. For bus, the commuting travel time includes the time for a person to walk to the bus stop and the time waiting for the bus to arrive. For bicycles, the average speed is 13.5 km/h.
3. Access to mobility service, which is defined as the share of population living within the studied area that have a proper access to a sustainable mobility service. The maximum distance that a person accepts to walk to use a transportation service is assumed to be 400 m.

#### 7.3.2.4 Methodology for data analysis

For the analysis of urban infrastructure, distances were computed using the Google Maps service, and both green and residential areas were computed using the Google Maps Area Calculator tool. The area of institutions and commercial buildings were measured by personal inspection, using a laser device. Furthermore, bus stops, bike roads, and bicycle parking were also identified by personal inspection to assess their existence and maintenance conditions.

The overall characteristics of mobility demand in the area were studied in a previous Chapter using quantitative mobility indicators to evaluate the opportunities that the studied area offers for communication with other zones of Montevideo. According to Calthorpe (1993), TOD is conceived to promote non-motorized transportation modes or public transportation instead. However, some studies (De Vos J., 2014; Kitamura and Mokhtarian, 1997) that travel behavior are more associated to human attitudes than to land use characteristics, influenced by certain factors as income, or household composition. On the other hand, Papa and Bertolini (2015) stated that the travel behavior can change if other urban characteristics significantly change too (e.g., universal accessibility, good connectivity, safe neighborhoods and attractive streets that promote walking, etc). All these factors are taken into account in the analysis. Public transportation is a specific focus of the study, since it is key for promoting sustainable mobility. Public transportation is a rational alternative to private transportation modes that have high impact in the environment (automobiles, motorcycles) due to pollutant emissions and greenhouse gases.

## 7.4 TOD-based sustainable mobility analysis for Parque Rodó neighborhood, Montevideo, Uruguay

The studied area was analyzed through TOD principles followed by decision makers and urban planners to strengthen their communities, and relevant indicators for sustainable development (Renne, 2009).

### 7.4.1 Land use

Land use is one of the most relevant considerations for TOD-based design and analysis. Land use must be properly integrated with transportation planning, to account for the different activities that citizens perform and need to have access to. Accessibility, pedestrian connectivity and friendliness, and the built infrastructure are three important concepts to consider (Vale, 2015). Land use and public transportation must be harmonized to provide a useful alternative to private transportation, in order to reduce the use of automobile (Nigro et al., 2019).

Five categories were considered in the land use analysis: commercial, residential, educational, recreation, and green zones. The distribution is reported in Table 7.1, including information about the total area, the built area (when corresponds) and the percentage over the total.

**Table 7.1:** Land use in the studied area.

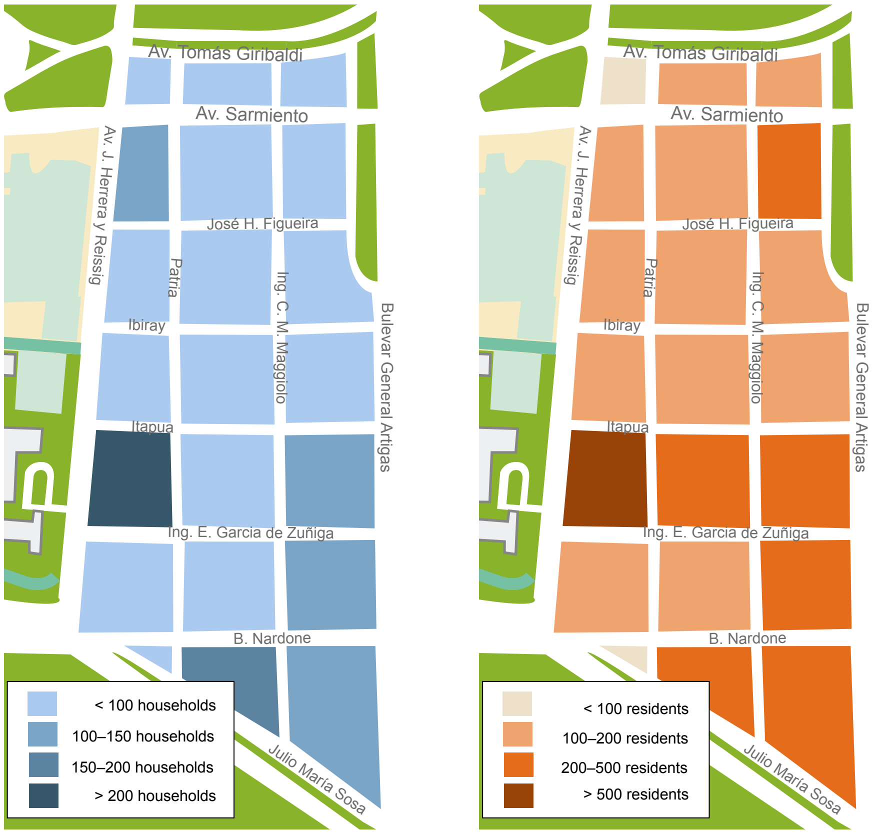
| *category* | *total area* | *built area* | *percentage* | *notes* |
|---|---|---|---|---|
| green zones | 216524.4 $m^2$ | - | 40.6% | - |
| residential | 180788.7 $m^2$ | all | 34.0% | 234 households |
| recreation | 85910.1 $m^2$ | - | 16.1% | - |
| streets | 33598.6 $m^2$ | - | 6.3% | - |
| educational | 10969.7 $m^2$ | 33785.3 $m^2$ | 2.0% | 3 institutions |
| commercial | 5752.0 $m^2$ | 6836.4 $m^2$ | 1.0% | - |

Results in Table 7.1 demonstrate that the studied zone is mainly residential, and has a large share of green an recreation areas, which certainly contributed to sustainability. Educational and commercial uses account for a very small part of land in the studied zone. All residences have a public transportation stop within a radius of 200 m. For analyzing the relationship between the transportation network and land use, the node-place model (Bertolini, 1999) is applied. The node-place model is a territorial organization model that analyzes how transportation and land use interact with and influence to each other. The model postulates that improving transportation offer creates a favorable situation to improve and diversify land use, and vice versa. The potential for development is determined by a set of relevant indicators. Indicators related to the ‘place’ include number of directions served by public transportation, daily frequency (number) of services on working day, and number of stations within 20 minutes of travel. Indicators related to the 'place' include number of residents, residential density, number of workers (often dissagregated in education/health/culture, administration/public services, industry, secondary sector, tertiary sector), number of jobs, and degree of functional mix. According to the node-place model, transportation and land use are well harmonized and good accessibility is provided. Node index for all public transportation stops in the studied area are between 0.62 and 0.84, whereas place index are between 0.70 and 0.89. Values are similar to those obtained for the best station areas in metropolitan neighborhoods of Lisbon, in the study by Vale (2015). In turn, the low difference between the squared difference between those indexes demonstrate a correct node-place balance, suggesting that the transportation supply is adequate to match the potential demand created by the existent land uses in the studied area.

The reported values is analyzed according to related TOD concepts, such as density and compactness/mix. Walkability is considered too, to analyze the balance between transportation offer and land use, as a surrogate of demand (Vale, 2015).

### 7.4.2 Density

Urban density is a fundamental principle of sustainable development. Dense development sustains public transportation, shortens travel distances and keeps travel cost affordable. For dense cities, the TOD paradigm supports building up instead of building out to avoid urban sprawl. The study analyzed this category through two criteria: residential density and commercial activities density. The residential density correspond to 13.18 residents/ha, and the commercial activities density (over total uses) correspond to 0.1%, considering the total number of households, educational buildings, and commercial stores. These values confirm that the studied area is most a residential (rather than commercial) area of the city. Figure 7.2 presents a description of household and population numbers in the studied zone, at the census zone level (city blocks).




(a) Households (b) Population

**Figure 7.2:** Number of households and population in the studied zone

Values reported in Figure 7.2 show a high correlation between the number of households and population, with a few exceptions on central blocks of the studied area. The average value of residents per household is 2.08, with a standard deviation of 0.35 (16.6%). The results distribution is normal according to the Jarque–Bera test applied to analyze if the skewness and kurtosis match a normal distribution. Both households and population are mostly concentrated in a specific block nearby Engineering Faculty, which is an attractor of population and commercial activities in the zone.

### 7.4.3 Compactness and mix

Land use in the studied area is diverse and it shows a reasonable compactness and good degree of functional mix.

Compactness is relevant because citizens prefer traveling shorter distances (independently of the transportation mode used) to perform their daily activities, which implies the closer the activities are from each other, the less time required. The study identified that residents have first-needs (supermarket, pharmacy, food stores, etc.) and other stores (veterinary, gift shop, printing house, supplement store, etc.) only a few blocks away from home/work. Stores to pay services (public and private) are also nearby.

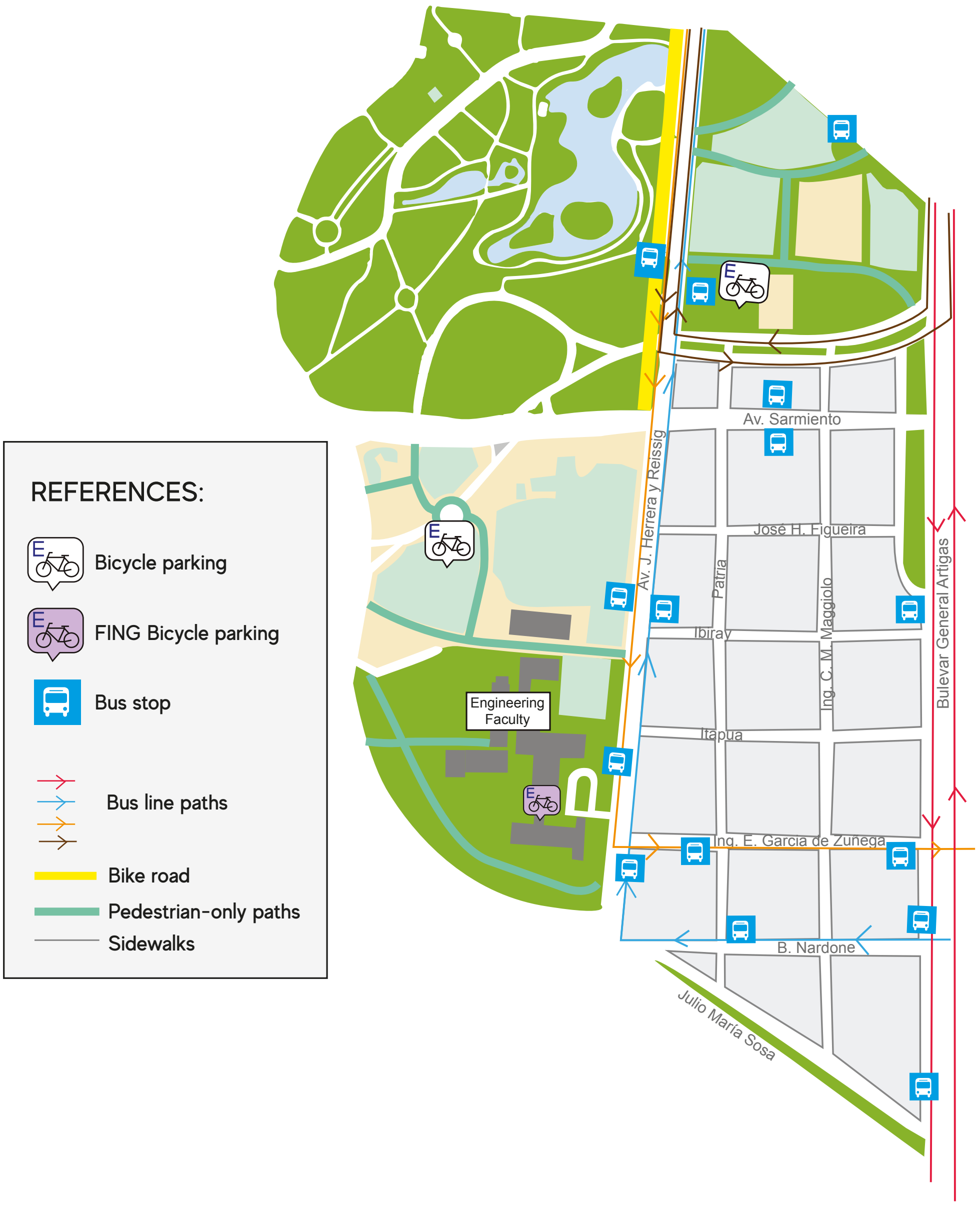



**Figure 7.3:** Mobility information of the Isle

The map in Figure 7.3 present accurate information about the location of different services, bus stops, bicycle parking, pedestrian only paths, and Map in Figure 7.4 identified land uses in the studied area. The upper map reports the information for the studied area (buffer area of 400 m), whereas the map at the bottom reports services in the extended area (buffer area of 800 m).


**Figure 7.4:** Information about mobility and services in the studied area (buffer 400 m) and the extended area (buffer 400 m)

### 7.4.4 Public spaces

Public spaces contribute to enhance the beauty and environmental quality of neighborhoods, and also contribute to socialization and sustainability. The studied zone provides 0.217 $km^2$ of green areas, which corresponds to 40.6% of the overall land. The average distance for residents walk to a green area is 200 m.

Regarding maintenance conditions of the green areas, municipal workers are responsible for keeping green and public recreation areas clean and in proper conditions. Green areas also contributes to improving air quality and the overall environment conditions. In this regard, the studied zone is within the most clean areas in the city, according to the Environment Ministry (www.gub.uy/ministerio-ambiente).

### 7.4.5 Transit/public transportation

A good public transportation service should connect many distant areas, creating a more accessible and equitable city. High bus frequencies and the existence of a bus stop in the proximity of residential areas is one of the principles of the TODs approach. The study identified 12 bus stops in the studied area, and residents can walk to them in less than 5 minutes from their homes. During working days, the bus service operates with a mean frequency of 12 to 17 minutes on peak hours (7:00 to 22:00), 25 to 35 minutes from 22:00 to 0:00, and low frequency between 0:00 and 5:00. On weekend days the demand is lower and so the frequency.

In general, the maintenance conditions of bus shelters is low. The original design presents a sitting bench, a roof, a commercial panel, lighting, bus line signage and a trash bin. However, the majority of commercial panels, lightening and bus line signage are damaged; 7 out of 10 have the sitting bench, 15 out of 17 already have the roof, and the trash bin is missing in all of them. Moreover, 8 bus shelters are located closer the corner of the street, blocking the visibility for pedestrian that are crossing the street.

Regarding demand, it closely matches the population and commercial activity in the zone, as represented in the heatmap of ticket sales in Figure 7.5. Bus stops near Engineering Faculty have all more than 10000 trips per month, demonstrating that it is an attractor in the studied zone. Two bus stops in Bulevar Artigas and one of the electric line E14 in Sarmiento have a very low number of ticket sales, suggesting that they are not used frequently by people commuting from the studied zone.

### 7.4.6 Connectivity, ciclying, and walkability

Safety and comfortable walking and cycling contribute to the TOD approach. Relevant indicators to evaluate those sustainable mobility means are the proportion of pedestrian and cycling routes, intersections density, and the network connectivity. The proportion of cycling and pedestrian routes over the total road network is just 0.2%, a very small proportion. The intersection density in the area is 0.2 and the gamma index connectivity is 0.3, which are reasonable values for a residential neighborhood.

Regarding design and maintenance conditions of sidewalks, the study analyzed the area through guidelines provided by municipal technicians and city

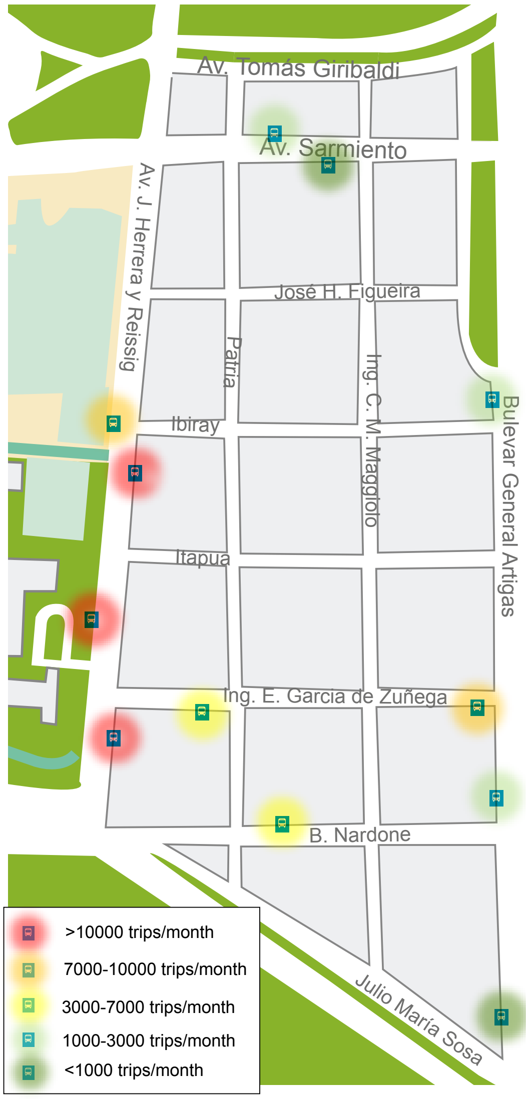



**Figure 7.5:** Heatmap of ticket sales in the studied zone

planners to facilitate the design and construction of sidewalks (Dos Santos et al., 2019), to encourage people to walk more in their daily routine. Eight principles of sidewalks are detailed in the guideline: proper size, universal accessibility, safe connection, clear signage, attractive space, permanent security, quality surface and efficient drainage.

Overall, sidewalks on the studied area present a proper width that provides pedestrians a comfort and safety walking. Also, the studied area offers universal accessibility with curb ramps in every corner and at the entrance of pedestrian-only paths, providing easy access for people with reduced mobility (e.g., elderly and wheelchair users), people with temporary limitations, pregnant women, or parents with baby strollers.

Public lightening is located in all sidewalks in the area, increasing the sensation of security while walking. In turn, vegetation is plentiful in the studied area, motivating people to walk and occupy urban public spaces. However, the connections of sidewalks to other means of transportation presents some issues, such as the lack of crosswalks, poor quality paving, crude design of urban furniture and vegetation, no tactile surfaces integrated into the sidewalks and few informative signage. Furthermore, the studied area present few initiatives to discourage the use of car in the area. Figure 7.6 presents an evaluation of the design and construction of sidewalks in the studied area, analyzed through the eight principles of sidewalks formulated by Dos Santos et al. (2019). The applied criteria are: *high*, when all elements are fulfilled, *medium*, when at least half of the elements are met,and *low*, when the elements of the principle are not met.

| PRINCIPLES OF THE SIDEWALK | ELEMENTS | HOW DOES IT CONTRIBUTE TO THE QUALITY OF SIDEWALKS | EVALUATION & COMMENTS (LOW, MEDIUM, HIGH) |
|---|---|---|---|
| Proper Size | Pedestrian zone / Furnishing zone / Frontage zone | Provides pedestrians with comfort and safety | HIGH |
| Universal Accesibility | Curb ramps / Tactile surfaces / Running slope | Contributes by making urban space more inclusive | MEDIUM (Curb ramps only) |
| Safe Connections | Connectivity/ Corners / Crosswalks | Facilitate and prioritize walking | MEDIUM (Connectivity, corners and public transport stops) |
| Clear Signage | Informative signage / Pedestrian | Provides information about the city at the scale of pedestrians. | MEDIUM (Only informative signage) |
| Attractive Spaces | Vegetation/ Urban furniture | Motivate people to walk and occupy urban public spaces | MEDIUM (Abundance of vegetation, poorly urban furniture) |
| Permanent Security | Public lighting / Active frontages | Increases the sensation of security while walking | MEDIUM (Only Public lighting) |
| Quality Surfaces | Site-cast concrete / Porous concrete | Provide pedestrians with comfort and safety | LOW (irregular pavement, some tiles are broken) |
| Efficient Drainage | Cross slope / Rain garden | Contributes to maintaining sidewalk functionality. | HIGH |

**Figure 7.6:** Evaluation of the design and maintenance condition of sidewalks.

The bicycle path width in the studied area is 2.0 m (two-way bicycle lines with a yellow centerline), well below the minimum recommended of 2.5 m.For the intersection crossing markings, color pavement is used to increase visibility within conflict areas or across entire intersections. Elephant feet marks are also used as an alternative to dotted line extensions, to offer increased visibility.

Figure 7.7 shows examples of the bicycle path design in the studied area and figure 7.8 summarizes relevant features of the NACTO reference guideline.


**Figure 7.7:** Bicycle lane design in the studied area (Herrera y Reissig Avenue)

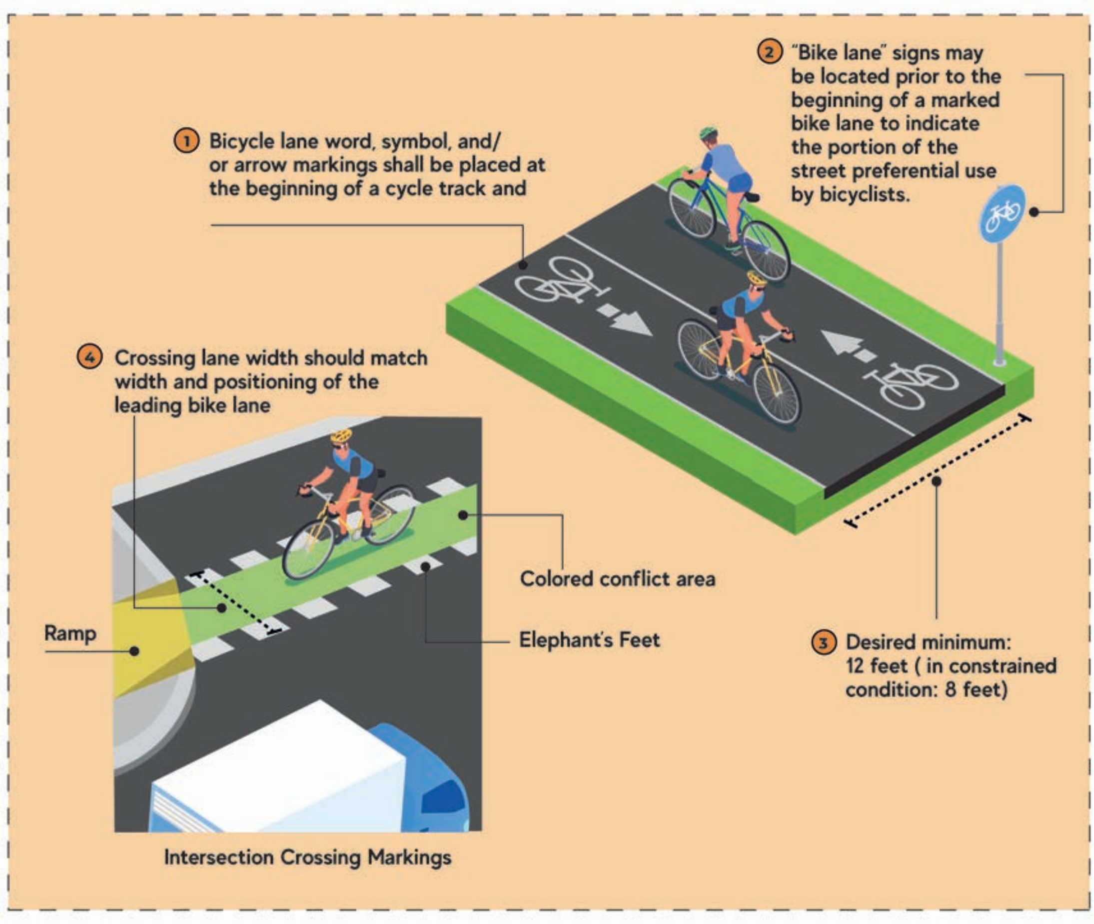



**Figure 7.8:** Relevant features of the NACTO urban bikeway design guide

### 7.4.7 Mobility demand and shift to sustainable transportation modes

Regarding the number of trips from/to the studied zone, the main findings of the analysis is that many people travel from/to near locations: one third of the surveyed people commute from/to less than 3 km away, and 60% from a maximum distance of 5 km). This tendency suggests that the impact of implementing sustainable mobility initiatives following the TOD approach, specially focused on accessibility to nearby locations, will be notable.

Figure 7.9 reports the accumulative percentage of trips according to the travel distance from/to each neighborhood in Montevideo.

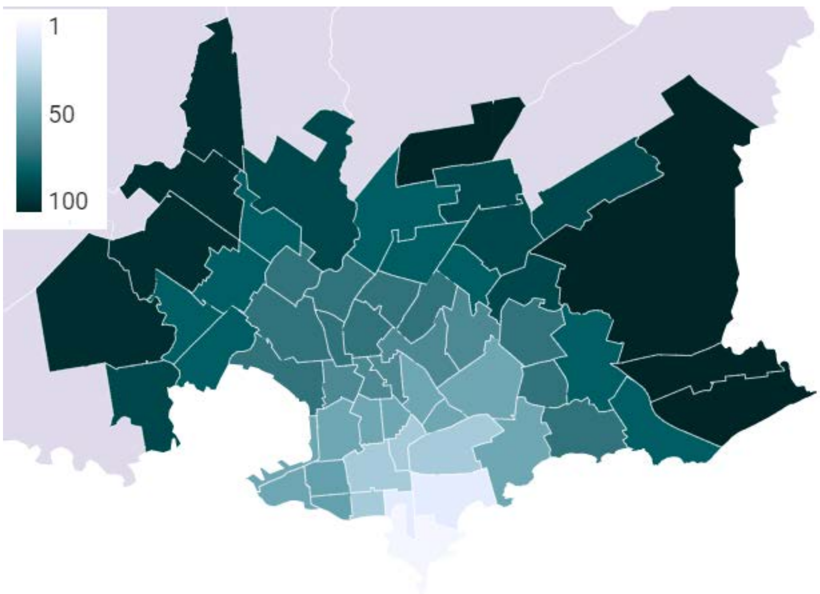



**Figure 7.9:** Ccumulative percentage of trips from/to neighborhoods in Montevideo

The study revealed that 95% of people make a round trip and more than 90% commute from/to the same location at least three times a week. These results demonstrate that mobility demands in the studied zone are regular and steady, thus supporting the pattern detection analysis developed in this article.

In line with the analysis of travel distances, the study also evaluated the average commuting travel times from/to the five most demanded origin/destination of trips to/from the studied zone, which are less than 4 km away from the studied zone. Results are reported in Table 7.2. One neighborhood that is far away (Prado, 8 km from the studied zone) is also included to analyze the scalability to larger distances (walking times are not reported for Prado, since no travels are registered for that mode).

**Table 7.2:** Commuting travel time to Engineering Faculty from the five most frequent neighborhoods as origin/destination of trips (in minutes).

| *neighborhood (average distance)* | *bus* | *bicycle* | *walking* | *car* |
|---|---|---|---|---|
| Parque Rodó (∼ 1.0 km) | - | 4.4 | 12.0 | 5.7 |
| Cordón (∼ 2.5 km) | 18.9 | 11.0 | 30.0 | 12.0 |
| Tres Cruces (∼ 3.0 km) | 21.2 | 13.3 | 36.0 | 15.2 |
| Pocitos (∼ 3.5 km) | 28.4 | 15.5 | 42.0 | 17.0 |
| Centro (∼ 3.7 km) | 24.4 | 21.4 | 44.4 | 20.8 |
| Prado (8.0 km) | 44.4 | 35.5 | n/a | 28.8 |

Considering nearby neighborhoods (Parque Rodó, Cordón, Tres Cruces, and Pocitos, located up to 3.5 km from Engineering Faculty), bicycle is the fastest transportation mode. This is a relevant result, since a large percentage of travels have origin/destination in those five neighborhoods. For Centro and other neighborhoods up to 8.0 km, car has similar travel time than bicycle and both are faster then bus. These results suggest that the efficiency of public transportation (regarding travel time) is not optimized to provide an appropriate quality of service. Despite the fact that bicycle is the most convenient transportation mode, this is not clearly reflected on the existence and length of bicycle-only lanes or bicycle parking, as commented in the analysis of infrastructure.

Concerning the shift to sustainable transportation modes, a good coordination between activities and the transportation network does not guarantee that people prefer using sustainable mobility options instead of using their own car. To promote sustainable mobility, other measures such as parking and road use must be regulated to discourage the use of private transportation.

According to NACTO, the maximum recommended speed limits are 15 km/h for shared streets or alleys, 30 km/h for minor streets, and 60 km/h for major streets that have well-protected lines for pedestrians and bicycles. These values are defined to minimize risks to pedestrians and cyclists. In the studied zone, the car speed limit is 45 km/h on streets and 60 km/h on avenues, which do not provide protected lines for bicycles. Regarding car parking regulations, there are no restrictions and no fee is charged for parking on the streets in the studied area. Furthermore, there are three free car parking areas and many open places to park in. Overall, the studied area does not meet with the recommended speed limit and with other policy regulations in order to reduce the use of car and increase sustainable mobility. In turn, the electric bus service that operates in the area account for a very small share of trips, suggesting that it has not being optimized to provide a proper coverage. This fact hinders the applicability of sustainable public transportation in the studied area.

The infographic in Figure 7.10 reports TOD-related information of the studied area, including the percentage of land uses and their total area, the total distances of sidewalks and pedestrian paths, the number of bus stops and bicycle parking, and the maintenance condition of bicycle path, sidewalks, bus shelters, green areas, and recreation areas.

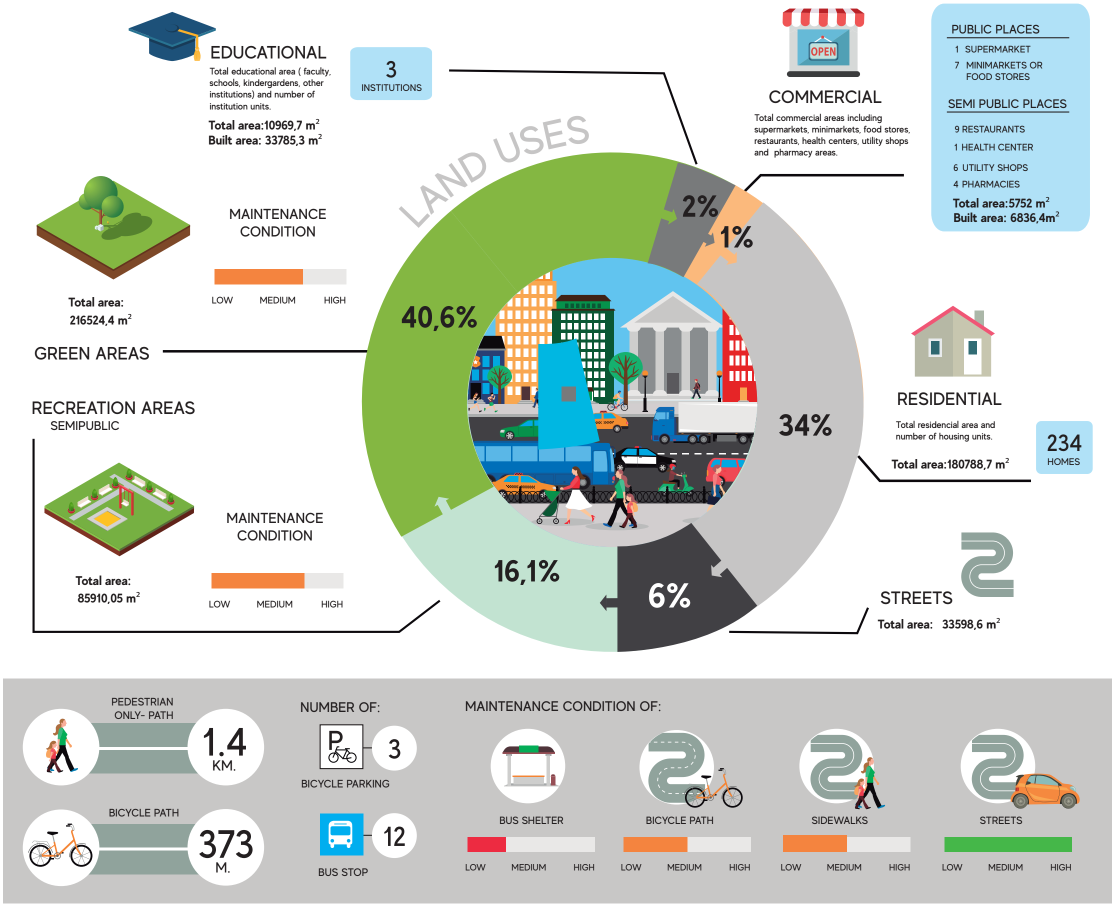



**Figure 7.10:** TOD infographic

## 7.5 Suggestions and recommendations to improve sustainable mobility under the TOD paradigm

Taking into account the results of the empirical analysis developed in the studied zone, there is significant evidence to confirm that sustainable mobility in the studied area can be enhanced considering TOD principles, by applying specific suggested actions.

*Extend the bicycle network.* The studied area offers a very short bicycle network. The analysis suggest it should be extended along main avenues. The bicycle lane along Sarmiento Ave. should connect the studied area with the seaside, whereas the bicycle lane along Gonzalo Ramirez and Julio Herrera y Reissig Ave. should be extended to connect two important education centers (Economic and Communication Faculty) with Engineering Faculty and Aulario Massera. In turn, a new bicycle lane along Julio Maria Sosa Ave. would be very useful to connect the studied area with the shopping mall and many commercial stores nearby. Finally, a bicycle lane along Bvar. Artigas would be the main connection with many neighborhoods of Montevideo, the seaside, and Terminal Tres Cruces (public transportation station).

*Install signals for safe pedestrian crossing.* A proper signaling of pedestrian crossings improves walkability, safety, and also promotes a better pedestrian behavior. Few signals were detected in the studied area, so this is a specific problem to be solved. In addition, the study recommends installing a pedestrian crosswalk in front of Engineering Faculty, the main attractor of activities in the area, to improve accessibility for students and workers.

*Reallocate bus shelters for safe crossing.* The study detected six bus shelters located very closed to street corners. That location means that pedestrians do not have adequate visibility when crossing, putting them at risk of a serious accident. The study recommend reallocating those six bus shelters to mid-block locations, which offer significant advantages regarding the minimization of sight distance problems for both vehicles and pedestrians, and also provides more spacing on waiting areas, resulting on less pedestrian congestion (Transportation Research Board, 1996). The possible disadvantages of the proposed modification are related to the additional space for no-parking zones nearby the bus stop and a slight increase on the walking distance for commuters. But their negative impacts are very minor, since walking distance are less than 300 m for all bus stops and parking is not allowed on avenues where the most demanded bus stops are located. In any case, car parking should be prohibited or discouraged in those locations where it implies a risk to pedestrians and other vehicles.

*Re-pavement damaged sidewalks.* As reported in the analysis of the design and maintenance condition of sidewalks in Figure 7.6, several defects were detected, including uneven pavement, broken tiles, etc. The study recommends re-pavementing poor-quality sidewalks, especially those damaged by tree roots, which pose a serious risk to universal accessibility in the studied area. Also, this issue must be considered for the selection of trees, to avoid them cracking and raising the sidewalks. In relation to universal accessibility, the surfaces of the sidewalks must be firm and leveled, for the adequate use of wheelchairs, the elderly, or people with temporary o permanent walking limitations.

*Add tactile surfaces to guide blind or visually impaired people.* The area does not provide elements to allow safe walking of visually impaired people. Guides are also missing on bus stops and other relevant locations and they must be properly installed to provide and improve universal accessibility.

*Improve the condition of bus shelters.* Comfort on bus shelter improves the image of public transportation. The study recommends a suitable design to prevent bus shelters from being so vulnerable to vandalism. Concrete or other highly resistant materials must be used. In addition, the design must provide better protection for bad weather conditions, especially for strong wind and rainy days. Every bus shelter must provide a garbage bin and a proper bench with enough space for people to sit comfortably and wait for the bus to arrive.

*Promote walking and interaction with the environment.* The study demonstrated that sidewalks play an important role in encouraging the interaction between people and the urban environment. Several actions must be developed to provide a better and more pleasant experience for pedestrians, including: improving information to guide pedestrians to reach their destinations, providing better and more functional urban furniture and vegetation (planters, garbage bins, benches, etc.), to make the environment more attractive and enhance the walking experience. These actions will certainly encourage people to walk more, in a more attractive environment.

*Implement car parking regulations and reduce maximum driving speed.* These actions will certainly discourage the utilization of automobiles and enhance traffic safeness on the studied area. Articles of NACTO organization present many examples where important cities worldwide have increased the use of sustainable mobility means (walking, cycling, and public transportation) by lowering the the speed limit to 30 km/h in residential areas, whereas traffic accidents have also reduced.

## 7.6 Summary

This chapter presented an empirical analyzing of sustainable mobility under the TOD paradigm in The Isle, Parque Rodó neighborhood, Montevideo, Uruguay. Relevant indicators were computed in the analysis, to establish the current situation and the relationships between land uses, activities, and sustainable mobility. The methodologies applied in the study included urban data analysis to identify a spatial/functional definition of the studied area, using operational data, personal inspection, and a survey performed in/situ to people commuting from/to The Isle.

The main findings of the analysis are related on the characterization of several TOD concepts and metrics, related to sustainable mobility. Bus stops are properly located, less than 5 minutes walking from the residents' homes, and the frequency of buses is good (15 to 35 minutes). However, the maintenance condition of bus shelters is low. The demand closely matches the population and commercial activity, and it is very steady: 95% of people make a round trip and more than 90% commute from/to the same location at least three times a week.

Walking and cycling are promoted in the studied area as the main sustainable mobility means. An electric bus line also operates in the zone. Sidewalks have a proper design and drainage, and offers good security and accessibility. However, the quality of surfaces is low. The bicycle path width only covers a very reduced distance. Cycling infrastructure is correct, but the lane width is below the minimum recommended. Few measures to discourage the use of cars are implemented, although people recognize they are willing to shift to sustainable transportation modes.

From the results of the analysis, relevant suggestions were formulated to improve sustainable mobility considering TOD concepts. The most important are extending the bicycle network, installing signals and reallocate bus stops for safe pedestrian crossing, improving sidewalks and bus shelter conditions, improving accessibility of blind or visually impaired people, and implementing car parking regulations and reduce maximum driving speed. Overall, land use in the studied area is diverse and it shows a reasonable compactness and good degree of functional mix, which make it suitable for applying TOD urban planning approach.

Based on the results of the analysis, specific recommendations are provided to develop a TOD-based approach to improve sustainable mobility in the studied area. The main goals of the proposed suggestions are related to improve the walking experience, provide universal accessibility, promote walking and bicycle, and the interaction with public transportation. This is a direct contribution of the reported research, since no previous similar studies have been developed in Montevideo.

# Chapter 8

# Conclusions

This thesis studied sustainable mobility initiatives implemented in Montevideo, Uruguay and analyzed a specific zone of Montevideo (The Isle, in Parque Rodó neighborhood) to evaluate the possibility of implementing a sustainable mobility plan for the area.

The study presented a review of the main related works of sustainable mobility and Transit Oriented Development developed in Uruguay and worldwide. Then, the study presented sustainable mobility initiatives that have been developed in Uruguay and analyzed the electric bus, public bicycles, and electric scooters through quantity and qualitative sustainable mobility indicators. Additionally, the study analyzed the current mobility reality of The Isle (an area located nearby Engineering Faculty, in Parque Rodó neighborhood) applying quantitative and qualitative indicators to characterize the mobility demands of the zone. A survey was performed in-situ, collecting subjective opinions from people commuting to/from the studied area, to gather mobility information. Finally, the thesis evaluated The Isle using concepts from Transit Oriented Development, a planning approach for sustainable development. Relevant indicators were computed in the analysis, to establish the current situation and the relationships between land uses, activities, and sustainable mobility.

Results of the study confirmed that the coverage area of the studied sustainable mobility initiatives is a small fraction of the total area of the city, thus a significant part of the population of Montevideo cannot access to sustainable transportation modes. Regarding cost, public bicycle is the most affordable mode of transportation, and electric bus is the second best option, mainly because these two services benefit from subsidies and support from public finances. Public bicycle is also the fastest and the most ecological option for short and long distance travels, however in terms of comfort and pleasure, is the worst of the three studied transportation modes. Public bicycle, electric bus, and electric scooter provide intermodal connectivity between them, but there is a lack of intermodal integration between services.

The mobility analysis of The Isle, which was based on a survey performed to 617 persons who commutes to/from the neighborhood from/to other zones of the city, was an important contribution of the reported research since no previous analysis of sustainable mobility has been performed for specific zones of Montevideo. Results of the study indicate that the area is fully covered by all the studied transportation modes (bus, bicycle, and electric scooters). However, in terms of sustainable mobility, the neighborhood lacks of a proper coverage, as the public bicycle initiative does not operate in the area and electric public transportation only did 3.6% of the total trips in 2016–2019 through the studied area. The survey reported that more than half of the trips from/to the studied area are made by bus resulting also the most popular transportation mode for distances longer than 2 km. This is a relevant result, because, according to the survey, more than half of the persons that currently travels using non-sustainable transportation modes would be willing to change to electric bus. Thus, the modal shift to electric mobility on public transportation turns to be an important topic to address in the studied zone. However, the shift from diesel to electric does not ensure the modal change to public sustainable transportation if buses still operate in the same condition as in actual service (too long routes with many stops, buses without air-conditioning and appropriate space,etc). Specific suggestions were provided in regard of the main drawbacks of current sustainable mobility initiatives in Montevideo.

Regarding the mobility analysis in Parque Rodó neighborhood, one important result is that more than half of the surveyed trips involve distances shorter than 5 km, i.e., suitable distances to commute by bicycle. The study also reported that a quarter of the interviewed people are willing to switch to bicycle as a sustainable mobility alternative. Also, the analysis of the zone applying TOD concepts it has sidewalks with proper design and drainage, good security and good accessibility of the area in general. However, the quality of sidewalks is low, bicycle path only cover a small stretch in the area. In general, the lack of infrastructure discourages people to use the bicycle or walk for commuting to/from the studied zone. Thus, improving the mobility conditions for bicycles and pedestrians turn to be an important topic to address in the studied zone. Furthermore, bus stops are properly located, less than 5 minutes walking from the residents' homes, and the frequency of buses is good (15 to 35 minutes). However, the maintenance condition of bus shelters is low. The mobility demands closely match the population and commercial activity, and it is very steady: 95% of people make a round trip and more than 90% commute from/to the same location at least three times a week. From the results of the analysis, relevant suggestions were formulated to improve sustainable mobility mostly focused on improving infrastructure (bicycle network, sidewalks, bus shelter,etc), traffic efficiency and accessibility.

Overall, the analysis of the three sustainable initiatives in Montevideo and the study of the sustainable mobility situation and demands of Parque Rodó neighborhood are valuable tools for helping academics, transportation companies, and stakeholders to analyze and evaluate possible solutions to implement sustainable mobility plans. The reported case study in Parque Rodó provides a basis for building more powerful surveys and data collection activities to better understand sustainable mobility in the whole city.

The main lines for future work are related to extend the analysis, by including some studies that were not taken in consideration, e.g., discussion of the use of automobile in the city (traffic volume data, number of traffic accidents, level of air pollution) and the measures that the city of Montevideo has taken to overcome with the problems generated by the automobile. For instance, building specific origin–destination maps to account for the most demanded travels to/from Parque Rodó neighborhood and performing a deep study of the reasons why people would be willing to change to sustainable transportation modes and a deeper analysis of public acceptance via global interviews. The analysis of different mobility needs is also an important line for future research, to assess the impact of sustainable mobility in Montevideo, focusing on its citizens. Regarding the replicability of the study, the proposed methodologies can be applied to characterize the mobility demands and the sustainable mobility analysis on other relevant neighborhoods in the city. Furthermore, the analysis can be also extended by considering other sustainable mobility indicators, relevant TOD concepts and studying best practices implemented on other cities, in order to contribute to the improvement of urban sustainable mobility in Montevideo.

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