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Influence of the built environment on gender usage of bike-sharing programs.

What are the effects of built environment on men an women activity patterns in Seattle bike-sharing system?

Beatriz Rodrigues Vieira Lopes

Dissertation presented as partial requirement for obtaining the Master's degree in Information Management

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INFLUENCE OF THE BUILT ENVIRONMENT ON GENDER USAGE OF BIKE-SHARING PROGRAMS

by

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Dissertation presented as a partial requirement for obtaining the Master's degree in Information Management, with a specialization in Information Systems and Technologies Management

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ABSTRACT

In recent years, there has been increasing attention to bicycle-sharing systems (BSS), making it one of the most rapidly growing transport services worldwide. Although there is a rise in popularity in BSS, the adhesion to this mode of transportation does not appear equal in gender, and this has increased the interest in exploring the factors affecting its usage. This study specifically identifies the factors that influence gender differences in bike-sharing programs. Using data compiled from Seattle's Pronto Cycle Share system between October 2014 and March 2017, this study contributes to filling the gender gap in bicycle-sharing literature. Using a multilevel approach to statistical modeling, which could easily be applied to other regions, this study took Seattle land use and built environment attributes of arrival and departure stations and correlated it to the bike-share usage for each gender. The results obtained show that there is, in fact, a correlation between bike-share usage and the built environment. The gender analysis concludes that even though males and females are both affected by the built environment, the magnitude of each variable's influence on the distinct genders is different. Specifically, there is more factor that affects women than men. The findings allow us to identify factors contributing to increased bicycle-sharing use in Seattle and provide recommendations on station size and location decisions.

KEYWORDS

Bike-Sharing Systems; Gender; Sustainable Mobility; Built Environment

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LIST OF ABBREVIATIONS AND ACRONYMS

IST	Intelligent Transport Systems
ICT	Information and Communications Technology
GDP	Gross Domestic Product
BSS	Bike-Sharing Systems
MBS	Melbourne Bike Share
POI	Points of Interest
GIS	Geographic Information Systems
SPSS	Statistical Product and Service Solutions
CBD	Central Business District

1. INTRODUCTION

1.1. RESEARCH BACKGROUND

Climate change and global warming are becoming the most relevant environmental concern; many scholars, organizations, and governments urge the population to live in a more sustainable manner (Evans et al., 2019). They are pivoting the focus previously put on mobility to sustainable mobility.

The climate crisis can only be solved when society changes its way of life, however, that can only happen if governments help encourage more sustainable development (Baldwin & Lenton, 2020). One of the efforts made by cities across the world to tackle this issue is the investment in sustainable urban mobility solutions since transportation is one of the key pollution sources in urban spaces (Potter, 2003). Furthermore, research has shown that sustainable urban mobility is an option worth considering when discussing options to better cities and increase the links between locations and transport (Banister, 2008; Holden, Gilpin, & Banister, 2019; Silva & Ribeiro, 2009).

To improve sustainable urban mobility, many leaders turned to bike-sharing systems thanks to the profound influence it has on cities. Bike-sharing services create a new transportation option, provide alternatives for people who want to use bicycles as a mode of transportation but do not have the economic power or the space to store a bicycle at home and allows people to move in a more environmentally friendly way. Bike-sharing can be linked to an increase of the cycling community, a decrease in greenhouse gases, and an increase in people's mobility (DeMaio, 2009).

However, aiming for sustainability in urban mobility is not enough; a city's mobility is only genuinely sustainable when access to different modes of transportation is possible for all people. For this to be possible, the supply of mobility services must be designed to consider various users, their socio-economic profiles, and, most importantly, their different needs.

Women worldwide are aware of the inseparable connection between gender and mobility and the effect the terms have on each other. Like many other areas, mobility is influenced by gender (Hanson, 2010). This happens because the role women play in society is still structured based on gender, and despite a slow change, gender gaps in various facets of life in society are still very much in (Lorber, 2010).

Women's decision to partake in bike-sharing systems as a mode of transportation hinges on many factors. Among them is the built environment. The spatial characteristics of the surrounding environments may be linked to the gender disparity in bike-share systems. Women's preference for bike-share programs depends on safety, land use, and public transit services (K. Wang & Akar, 2019).

All things considered, studying the impact the built environment has on each gender's usage of bike-sharing programs was identified as a relevant subject to pursue.

1.2. Problem Identification

Historically, many of society's concerns and problems were addressed with only the male perspective in mind. The traditionally male lens, used to design most societies' concepts, services, etc., has chiefly left out women, leaving them to fend for themselves (Criado-Perez, 2019). This phenomenon explains the significant gender data gap existing in our world.

We can identify this gap when looking at urban mobility. The absence of information on gender issues in mobility and the lack of mobility data and statistics acknowledging gender based differences has contributed to the fact that many of the problems women face while traveling are unacknowledgeable by men because the reality is that they do not nor will ever have to experience it. Actions should be taken to guarantee that the gender gap in mobility is filled and that a solution to improve mobility inequality is pursued.

There is consensus regarding how mobility patterns and behaviors are gendered - women's mobility patterns are distinguished by fewer and shorter trips and more use of sustainable travel options, such as walking and public transportation networks (Grieco & Turner, 2000; Hidayati, Tan, & Yamu, 2020; Miralles-Guasch, Melo, & Marquet, 2016). In addition, there has been some exploration into the root causes of the problem. However, there are still many contradictory literature results regarding the primary drivers of women's decision not to pursue bicycling as a mode of transportation in certain countries (Prati, 2018).

Furthermore, the different and often contradictory results justifying the difference in mobility between men and women tend to focus only on physical anatomy or social imposed factors (Rosenbloom, 2006), pointing us to the assumption that scientific research on this topic may be lacking. Additionally, the data commonly used in research on urban mobility is gathered through surveys and observation over a limited period or reduced space range, leading to a multitude of errors (Gauvin et al., 2020).

1.3. Research Question and Objectives

To help fill the gap mentioned above, this research intends to study the crucial factors related to gendered sustainable mobility, specifically bike-sharing services. As a result, the author intends to understand "How does the built environment shape gender usage of Bike-sharing programs."

Thus, this paper aims to combine the existing literature on bike-sharing programs and the gender differences in bicycling and understand the ways land use and built environment factors influence each gender in the use of bike-sharing programs. To achieve this goal, the research focused on analyzing a case study of Seattle's bike-sharing system as a proof of concept that can later be explored for other contexts, possibly Lisbon. The author chose the city of Seattle because the data from Seattle bike-sharing system program and the information that characterizes the built environment were accessible and attainable.

Hence, the approach addresses the following research questions:

> **Research Question:** What are the effects of the built environment on trip activity patterns in the Seattle bike-sharing system for men and women?
>
> It is crucial to define a roadmap with steps that will guarantee the accomplishment of the paper's milestones and objectives; therefore, the paper's primary efforts can be determined as:
>
> **Step 1:** Gather the data from the bike-sharing system with information regarding the trip id, origin and destination stations, trajectory, and time.
>
> **Step 2:** Investigate and identify the main spatial factors involved in the influence of bike usage based on the literature review.
>
> **Step 3:** Analyze and validate the relationship between the study variables, gender, built environment, and mobility.

1.4. Study Design

An extensive literature review was made to understand concepts and approaches when researching sustainable mobility and gender. The methodology in the initial phase consisted of reviewing existing literature to find proven spatial factors known for their influence on bicycle usage and recent studies about the theme. Further, considering the research questions outlined, the variables under observation were defined. The data collection also occurs in this phase of the dissertation. Subsequently, the data collected was treated with statistical techniques. Lastly, a Multiple Regression Analysis was held to test the earlier hypotheses.

1.5. Results and Contributions

The topic studied is particularly relevant since it can raise new opportunities for cities and urban planners to improve the city's options for sustainable mobility. This investigation is expected to help bike share system companies understand the best location for station docks and benefit users of said services. Further, this study will help implement measures and policies to attract more people to bike-sharing services. Thus, it is also expected that this investigation will help further understand the topic and lead to more debate.

1.6. Thesis Structure

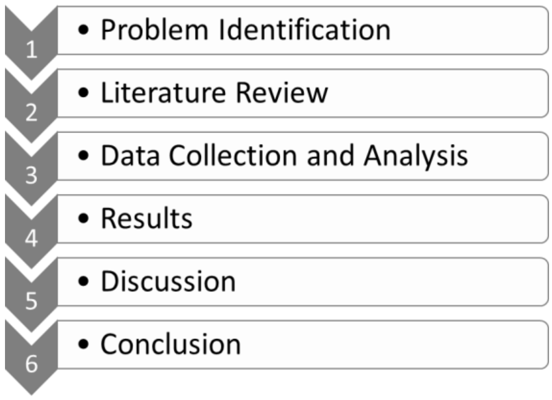

Figure 1 - Thesis Structure

The dissertation was divided into seven predominant chapters. Chapter one contains the introduction, where the context of the topic as well as the goals and the motivation of the dissertation can be found. The second chapter introduces the literature review - concepts of gender mobility, sustainable mobility, and the gender gap in cycling are presented in detail. Chapter 3 addresses the methodology applied, explaining the steps to achieve the intended analysis. Then, chapter 4 outlines the results obtained after following the methodology proposed in chapter 3. Chapter 5 contains the discussion of said results and their validation reliability. Lastly, in chapter 6, the conclusions are presented, and chapter 7 – the last chapter - contains the limitations and recommendations for future investigations.

2. LITERATURE REVIEW

For the development of any study, it is first needed to evaluate and comprehend how the subject was addressed in previous investigations and analyses. The main intention of the literature review is to check thoroughly into the state of the topic under discussion. The issues discussed in the following literature are gender, sustainable mobility, and the built environment.

A definition of mobility is provided to understand the thesis' content better. For the remaining content of the form, mobility will match the description provided by Hanson (2010), which states that mobility is the constant relocation of individuals throughout the day. It is essential to emphasize that the definition always applies regardless of the motive behind the relocation, whether it is a job, family-related, or entertainment. For qualifying measures, the literature used to describe mobility states that each person's movement pattern will always be concerning the number of relocations registered, the different ways they choose to use, and the reason behind said movement (Meurs & Haaijer, 2001).

2.1. SUSTAINABLE MOBILITY

The importance of leading a sustainable life increased in recent years as climate change has become an increasingly prominent global problem (Higham, Cohen, Peeters, & Gössling, 2013). In many European cities, statistics indicate that the urban areas house over 60% of the population (Commission of the European Communities, 2007). For this section of the population, more significantly present in urban centers, and for society, the climate crisis is a top priority (Banister, 2008). As a result, ecological and sustainable decision-making concerns have permeated into urban planning and have led many municipalities to thrive to achieve better sustainable urban development (Bak, Almirall, & Wareham, 2013).

One of the significant factors that contribute negatively to the environment is mobility since oil is the primary fuel source for transportation. Contrarily to other industries that are already taking significant steps to reduce emissions, the transport industry continues to be one of the main ones responsible for greenhouse gases. The accumulation of greenhouse gases in the atmosphere is a direct consequence of the continuing combustion of fossil-based energy and, therefore, the steady increase of the Earth's average temperature, commonly known as global warming (Chapman, 2007).

The evidence of the environmental consequences directly caused by mobility showed that the actual relocation of individuals is liable for a considerable portion of the emission: 76%, the remaining 26% being a result of manufacturing and losses in the supply system (Potter, 2003). Banister (2000) adds to all the previous consequences that mobility can have on the environment, the loss of quality of life due to air and sound pollution. These problems led many governments and political agencies to encourage and reinforce the need to address the issue more seriously, and the European Council to establish the goal to reduce the gas emission significantly by 2020 (Commission of the European Communities, 2007).

Jones's (2014) research reinforced the need to approach the problem differently; instead of focusing on creating cities that accommodate an unlimited number of vehicles, the solution should change our behavior to reduce the dramatic impact mobility has on the ecosystem.

As a result, the concept of sustainable mobility is introduced. The first time the notion of sustainable mobility was presented was in 1992 by the European Communities Commission. The knowledge of mobility's impact on the environment, despite being known, was not yet fully comprehended. The definition accounts for the importance of guaranteeing the containment of possible damaging effects to the environment while both economic and social duties of transportation are accomplished (EC, 1992).

Banister (2008) defines sustainable mobility as the ability to, with the aid of technological evolution and advances, decrease the number and lengths of voyages while motivating and inciting the population to change to a more environmentally friendly mode of transportation to achieve more effective and productive transportation. According to Lam & Head (2012), sustainable mobility implies the attainability to relocate to any location with comfort, convenience, and within a budget with low environmental consequences.

Therefore, according to the literature mentioned, while some aspects differ, sustainable mobility can be summed as mobility focusing on reducing the environmental, economic, social, and geographical impact.

Arguments have been made that with the aid of urban planning, innovative technology, cities and European policies', financial stimulants, population engagement, and government support, it is possible to increase accessibility and convenience to the population (Lam & Head, 2012).

To implement sustainable mobility actions must be taken to find solutions to ensure urban territories have cleaner air, fewer congestions, and easier access to services.

2.1.1. Bicycle

The vital role cycling plays in sustainable urban mobility allows for growing consideration in the current study (Zhou, 2015). The connection between environmental benefits and bicycle use as a mode of transportation is undeniable (S. Handy, van Wee, & Kroesen, 2014). The reduction of the consumption of CO_2 due to the non-motor miles traveled, and the decrease in traffic congestion all help associate bicycles as an environmentally friendly mode of transport (Caulfield, O'Mahony, Brazil, & Weldon, 2017).

Besides the environmental benefits of cycling, many health and social advantages were reported. Cycling has a positive impact on health and can be present at a personal and public level (Deenihan & Caulfield, 2014). Fuller (2013) presented evidence of reducing stress and weight loss for bicycle users. Cavill et al. (2007) discovered that weight loss was not the only benefit created by the physical activity of bicycling, the reduction in cardiovascular disease, stroke, cancer, and type II diabetes were also among the diseases that helped. Additionally, the increase in mobility reported by the bicycle users all led to conclude the overall benefits of the bike-sharing system (Nair, Miller-Hooks, Hampshire, & Bušić, 2012).

2.1.1.1. **Bike Share**

The literature shows that in fast-growing urban areas, the choice of bicycles as modes of transportation is gaining ground relative to the car. Consequently, over the last decade, the number of cities implementing a bike-sharing system (BSS) as an alternative mode of transportation has exponentially grown. Data indicates that more than 60 countries have implemented a BSS in some way, this led to the implementation and maintenance of over 700 bike-sharing system programs (Kaplan, Manca, Nielsen, & Prato, 2015).

Additionally, the increase in mobility reported by the bicycle users all led to conclude the overall benefits of the bike-sharing system (Nair et al., 2012). Besides the environmental benefits of cycling, many health and social advantages of using BSS were reported (Fuller et al., 2013).

Nowadays, BSS is divided into traditional bike-sharing and free-floating bike-sharing. The former is classified by the fact that users must pick and drop the vehicle at a designated docking station, while the latter is categorized by the absence of bike racks or solid frames (Liu, Szeto, & Ho, 2018). This paper focuses on the docked bike-sharing system, and for that reason, all the literature and information regarding this mode of transportation will be referring to docked BSS.

As mentioned, the traditional bike-sharing utilization requires a user to check out a bike from a chosen docking station and then check in the bicycle after the end of the trip. The advantage of this system lies in the fact that the check out station and check in do not have to be the same, giving the user more freedom in their travel choices (O'Brien, Cheshire, & Batty, 2014).

Furthermore, technological advances and improvements have helped create a better bike-sharing system for the users. The current BSS include systems that prevent theft by creating electronic locking arbors, telecommunication systems that monitor the location of the bicycle at all time, and integrated interfaces that the users can install on their smartphone to facilitate the utilization experience (Li, Zheng, Zhang, & Chen, 2015). The literature characterizes the present bike-sharing system as the third generation bike-sharing program (DeMaio, 2009).

The incorporation of technology in BSS allowed for discovering other relevant data. The growing interest in BSS and the heavy amount of data generated by the bike-sharing system led many cities to conduct several BSS studies (Zhou, 2015). Many of these studies enabled an understanding of the users' mobility patterns and travel behavior. These researchers concluded that demographic analysis of the user could result in insights not yet considered in current literature (O'Brien et al., 2014).

Even though the data shows increased use of BSS, the utilization distribution does not appear equal in gender. Empirical data reveal that the BSS users are predominantly men (K. Wang & Akar, 2019).

The gender gap existent across BSS programs is manifested in cities across the globe. Statistics from the London BSS revealed that male users are responsible for 82% of trips registered (Goodman & Cheshire, 2014). In Melbourne, the Melbourne Bike Share (MBS) also points to men being the primary user, reporting 76% of the total trip amount. The bike-sharing system of Brisbane, CityCycle, although with a slimmer gap still presents superior values for male users versus female users, with a proportion of male to female of 60% to 40% (Fishman, Washington, Haworth, & Mazzei, 2014).

Similar to the gender gap existent in Europe and Oceania, BSS programs in American cities also reported this discrepancy, indicating that the proportion of male users is higher than that of female ones. The statistic from CaBi – BSS from Washington DC – showed that 67% of the trips made by the registered members are made by men (Borecki et al., 2012). In New York, Citi Bike states that 78% of the total amount of rides are made by men, although the data showed that the percentage of female utilization is in many cases conditioned by the location of the bike share docks (Kaufman, Gordon-Koven, Levenson, Moss, & New York University, 2015).

Thus, the literature shows a consensus among researchers. All conclude that the well-established gender differences reported in cycling sharing programs point to the male user as the dominant user of this type of transportation service (Böcker, Anderson, Uteng, & Throndsen, 2020).

Some explanations were given to try to understand the disparity in the data. Among other causes like weather (Gebhart & Noland, 2014) and safety (Ravensbergen, Buliung, & Laliberté, 2019), the spatial characteristics of the surrounding environments were considered an influencer for the gender gap in bike share usage (K. Wang & Akar, 2019).

2.2. GENDER

The lack of access to certain services emphasizes the gender segregation already present in many cities (Chant, 2013). With the element of sustainable mobility playing a unifying role, such discrimination would reduce significantly and allow women to take full advantage of what the cities have to offer and, at the same time, help them reap their fundamental human rights (Gauvin et al., 2020). Hence the available literature establishes a clear connection between mobility and gender.

Gender is a concept challenging to define as it varies based on culture, personal experience, and environmental factors (Nightingale, 2006). The conservative perspective of addressing gender by acknowledging males' and females' culturally expected roles means placing women and men in stereotyping definitions of work and home responsibilities (Rowe & Hong, 2000): associating "bread-winning" duties with men and activities related to household responsibility, consistent with childcare, cleaning, grocery shopping to women (Hanson & Hanson, 1980).

Even though, nowadays, data shows that the distribution of women in the workforce is leveling, both in number and position, to the threshold held by men (Fan, 2015). There is a consensus among researchers that states that in couples where both partners have full-time jobs, the housework, for the most part, is still entrusted to the women (Criado-Perez, 2019).

Consequently, the gender gap in the bike-sharing system continues to grow (K. Wang & Akar, 2019). The reason behind the lack of women users in this mode of transportation raises some questions since the literature points to females being the gender more concerned with the environment (Kawgan-Kagan, 2020). Furthermore, women's mobility is much more environmentally sustainable than men’s. Women make shorter trips, choose sustainable travel options (e.g., walking) considerably more often than men, and are more avid users of the public transportation network, leading to fewer vehicle miles traveled (Hanson, 2010). According to some researchers, it is essential to mention that women, tendentially, are more open-minded and will with greater ease approve and participate in policies that have as objective the improvement of the environment, regardless of the personal cost (CIVITAS, 2014). Thus, women are more likely to conduct themselves differently if they think it will benefit society.

Even though research shows women are tendentiously more sustainable, the reason behind the gender gap in the bike-sharing system can be explained by empirical studies.

2.2.1. Gender Gap

Research has confirmed the existence of a severe gender gap in urban mobility, in general, in both developed and developing countries, clarifying the notion that women's and men's mobility patterns are in no way similar (Gauvin et al., 2020).

Women travel shorter distances for less time for various reasons for each trip – a chain of short trips. In other words, they are taking multiple temporary stops on a path to the final location as a way to accomplish all their responsibilities (e.g., going grocery shopping during the commute to work) (Shaw et al., 2020).

Studies on this topic have confirmed that men's travel behavior is in no way impacted by inputs like seniority, educational achievement, ability to drive, access to private transportation, area of residence and place of work, the number of children, or revenue. Simultaneously, every one of these variables affects women's commuting patterns somehow (Sánchez & González, 2016).

As mentioned before, the housework, for the most part, is still entrusted to the women, and the data on women's and men's travel patterns does not support the statement that both genders have equal division of childcare and homecare chores (Criado-Perez, 2019). Thus, allowing women to be more active members of the workforce, previously reserved for men, has fundamentally changed many families' households but not many women's mobility patterns. For example, married women are more likely to have their travel patterns impacted by family-related activities than their male counterparts (Paper, 2021).

The world was and still is built for men: routine activities in the day-to-day lives of men and women are experienced differently by the two genders. For the most part, many of society's concerns and problems that negatively affect women are typically not experienced or acknowledged by men. That is the case with mobility. The lack of sense of security when using public transportation, the locations of the public transportation network's stop areas, and the city's luminosity at night all impact the patterns of mobility of women (Loukaitou-Sideris, 2014). Research showed that women make travel patterns decisions conscientiously. This defense mechanism responds to the danger of being a woman and moving alone at certain times of the day and in certain parts of the city. The fear of being sexually assaulted is always present (Law, 1999).

Besides the evidence presented documenting the reasons that women's travel patterns are in many ways different from men's (Crane & Takahashi, 2009), many explanations have been given to find the answer behind the gender gap in BBS, specifically.

The primary evidence of the gender-bias use of BSS points to men being the more avid user of the bicycle in general (Wittmann, Savan, Ledsham, Liu, & Lay, 2015) in recreation and necessity cases (Akar, Fischer, & Namgung, 2013).

Safety is, to women, a significant impediment when considering bike-sharing as a mode of transport (Murphy & Usher, 2015). Women's perception of danger and security is much more rigid than men's (Delmelle & Delmelle, 2012). That does not mean men do not care for their physical integrity, only that it appears to be a motive not to cycle less often than it is for women; men, in general, are less averse to risk (Heesch, Sahlqvist, & Garrard, 2012). However, survey-based studies showed that the safety indicators presented by women were not only referring to traffic incidents but also personal attacks, assault, theft, accident with motorized vehicles, and exposure to air pollution (Prati, 2018).

The second hypothesis, explaining the gender gap in BSS, hinges on the fact that men and women use cycling for different purposes (Ravensbergen et al., 2019). As mentioned before, due to the various roles played in society, on average, more than 75% of the world's unpaid labor is still done by women, such as household, childcare, and elderly activities constant in any family (Criado-Perez, 2019). The nature of women’s activities impacts their trip purposes and, therefore, their choice of transportation, leading them to disregard bike-sharing options.

Bicycles, and many other forms of transport, are not designed for people traveling with kids, prams, strollers, and groceries or accompanying people with reduced mobility, which hinders women, the prime user with these needs, from taking advantage of these transportation modes (Paper, 2021).

In addition, spatial characteristics of the surroundings directly influence women’s decision to partake in BSS as a mode of transportation. Research shows there is a positive impact on the number of female users when the characteristics of the surrounding environment take into account variables like community, restaurants, coffee shops, grocery stores, fashion retailers, etc. (K. Wang & Akar, 2019).

By identifying the various factors that actively influence the movement pattern of each gender, it will be possible to decrease the gender gap existent in BSS. Since the different genders have specific needs, it is essential to find the factors that impact female ridership adhesion. Therefore, the level of adhesion to bicycling should be measured through the number of women using it, making them the indicator factor for a bicycle-friendly city (Akar et al., 2013). As stated before, the low adherence to BSS by women is partly explained by the spatial characteristics of the surrounding environments. There is reason to believe that addressing these may increase women's use of BSS.

2.3. BUILT ENVIRONMENT

Urban planners may use an array of terms - like urban design, land use, and transportation system - when talking about the concept of the built environment. For this reason, the concept's definition may sometimes be mistaken for one of the other concepts. Although there is a connection between these terms, the distinction of each notion is essential. This paper intends to define the built environment as within the tangible surrounding environment where human life occurs the inclusion of the transportation system, land use, and urban design (S. L. Handy, Boarnet, Ewing, & Killingsworth, 2002).

Therefore, the surrounding environments have a significant impact on the population. Studies have shown that the built environment directly influences peoples' lives. The way the population travels, shops, and works are all, in some manner, affected by the spatial characteristic of the surrounding environments (Cao & Zhang, 2016).

Furthermore, considering the influence spatial surroundings have on people's travel habits led to conclude that there is an increase in the utilization of sustainable mobility options when the built environment is well kept (Winters, Brauer, Setton, & Teschke, 2010). Many studies confirm the existence of a connection between the design of the surrounding environments and walking and bicycling. The reason behind this is the fact that these modes of transportation have a high incidence in urban areas and are mainly used for connecting destinations of the built environment, so if surrounding environments are not well maintained, and the infrastructure does not support pedestrians and bicycles, the tendency to use motor vehicle will increase (Frank & Engelke, 2005).

The number of people walking and bicycling can be easily raised when the built environment where human activities occur improves. The literature supports that the improvement of the built environment must be accounted for on various planes. It reinforces the need to consider taking action to create geographic closeness of urban amenities, supporting active mobility options (e.g., walking and cycling), focusing on bettering urban safety, supplying superior and easier access to transit, and creating more multifunctionality of green spaces (Pozoukidou & Chatziyiannaki, 2021).

Therefore, supporting active mobility options entails creating more opportunities where walking and cycling are the best choices for transport. BSS plays an essential role in this initiative. The introduction of bike-sharing experiences allowed the population to dismiss the car and choose a sustainable transportation mode (Moreno, Allam, Chabaud, Gall, & Pratlong, 2021) without having to purchase a bicycle.

However, focusing on the reinforcement of active mobility options is not enough the geographic closeness of urban amenities, the safety of the population, and the existence of green space must also be considered. Scholars contemplated as a possible solution the conception of more sustainable cities that would reduce the demand for carbon flue vehicles while simultaneously providing green outdoor spaces, security, and proximity between the different points of interest (POI) (Ding, Wang, Liu, Zhang, & Yang, 2017).

The “15-minute City” concept emerged as an answer to this need. Since the concept’s proposal in 2016, various opinions on the subject have been suggested. However, all authors agree on the central notion: The needs of the population, be they social, personal, or other, should be provided at a walkable or cyclable distance. Moreover, the different demographic groups should not at any point be left disadvantaged in the provision of basic amenities (Moreno et al., 2021).

Thus, for the 15-minute City to be able to answer the demand of the different users while accounting for factors like gender, age, occupation, and income, it must contain the six categories of amenities: (1) Education; (2) Health care; (3) Local administration; (4) Retail services; (5) Finance and telecommunication services; (6) Elderly care (Weng et al., 2019). The goal of bringing all the different amenities within a 15-minute distance is to enable the population to partake in living, working, supplying, caring, learning, and enjoying through a sustainable model of transportation and better quality of life (Amin, 2021). The table below (Table 1) presents the categories of amenities and some of their sub-categories.

Amenities Categories	**Sub - Categories**
Education	Kindergarten
	Primary school
	Middle school
	Libraries
	University
Health care	Hospital
	Pharmacy
Local administration	Public transport site
	Park and square
	Cultural venue
Retail services	Restaurant
	Shopping
	Entertainment
Finance and telecommunication services	Bank
	Post Office
Elderly care	Nursing home

Table 1 - Amenities within a 15-minute city

3. METHODOLOGY

This chapter intends to outline the methodology chosen for this investigation. The main objective was to present a method capable of verifying the research question - What are the effects of the built environment on trip activity patterns in the Seattle bike-sharing system for men and women?. Besides highlighting the previously concluded research on this topic, the chapter summarizes the procedures taken to verify the research question mentioned above.

3.1. VARIABLES

An extensive literature review was made to identify the most critical spatial characteristic factors that influence the gender gap in BSS. The core hypothesis is motivated by the literature, and therefore the following variables were identified: bike lanes, public transport services, restaurants, education facilities, green spaces, supermarkets, and streetlights. With the support of the literature, the following dimensions were defined.

3.1.1. Bike Lane

The expression “If You Build Them, Commuters Will Use Them” has been used to explain the direct impact bicycle infrastructure has on the number of users. Dill & Carr (2003) used this famous quote to illustrate that the low numbers of cycling commuters may be sole because there is no supply of bicycle facilities that offer protection from traffic. This variable has been a focus of attention in previous research. Studies support the notion that providing specific lanes and bicycling paths can increase bicycle use (Dill & Voros, 2007). The influence bike lane has on the adhesion to BSS appears consensual among scholars. The study indicates a correlation between bike lane availability and bike-sharing usage. The bivariate analysis concluded that at a significant level of 99%, there is a relationship between the number of bike-sharing trips and the availability of bike lanes (Buck & Buehler, 2011).

3.1.2. Public Transport Services

The proximity of the public transport services to the BSS station has received some attention in the previous investigations. However, there are contradictory outcomes on the correlation between bike share usage and public transport facilities (K. Wang & Akar, 2019). Some researchers defend that the correlation between the proximity to public transportation services and BSS should not be considered. Researchers claim that public transportation impacts BSS adhesion are not directly linked to the transportation service per se. Nevertheless, other factors, like atmospheric temperature and precipitation, play an essential role, concluding that the location of public transport cannot be solely considered (Gebhart & Noland, 2014). On the contrary, other investigations have stated that public transportation systems can better serve their users with the aid of BSS, allowing for bike-sharing systems to support public transport by improving last-mile connectivity (Tran, Ovtracht, & D'Arcier, 2015; Faghih-Imani & Eluru, 2015; Jäppinen, Toivonen, & Salonen, 2013).

3.1.3. Restaurants

The existence of restaurants – including coffee shops and bars – is crucial to analyzing the impact environmental surroundings have on BSS (K. Wang & Akar, 2019). However, there are contradictory outcomes. Some researchers concluded that there is no statistical significance in any models of long-term bike-sharing usage that can link the number and proximity of restaurants to increased use (Tran et al., 2015). On the contrary, studies found that BSS registers a higher level of arrivals and departures when there is proximity to restaurants (Faghih-Imani & Eluru, 2016; Faghih-Imani, Eluru, El-Geneidy, Rabbat, & Haq, 2014). This correlation between restaurants and the adhesion to BSS is then statistically explained by the fact that food-related enterprises create an increase of 1.7% in bike share trips (X. Wang, Lindsey, Schoner, & Harrison, 2016).

3.1.4. Education Facilities

When considering the built environment's impact on BSS, one vital factor to consider is education facilities – schools, universities, and libraries. A significant number of scholars linked the stations' proximity to universities to higher numbers of bike-sharing trips (El-Assi, Salah Mahmoud, & Nurul Habib, 2017; Faghih-Imani & Eluru, 2015; K. Wang, Akar, & Chen, 2018; X. Wang et al., 2016). Thus, the bike-sharing stations near universities have been associated with higher arrival and departure rate at a significance level of 95% (Rixey, 2013). One factor contributing to the high level of usage in universities is that BSS is considered a non-expensive mode of transportation, making it a prime choice for students, who generally have low to no income (Tran et al., 2015). However, some studies concluded that when dealing with children, the factors that influence the low and high number of kids using this mode of transportation are the distance between home and school, traffic vulnerability, confidence in the child's ability to cycle, and the existence of cycling infrastructure (Trapp et al., 2011).

3.1.5. Green Spaces

BSS stations near parks and other green areas registered greater levels of station action (X. Wang et al., 2016). Although for apparent reasons, working days register less arrival and departure volume than weekends and holidays (Faghih-Imani & Eluru, 2016). Therefore, green areas might have a more significant impact on bike share users that are not part of the working class; consequently, parks' impact on working commuters might be meaningless (K. Wang et al., 2018). The proximity to parks and other green spaces is a variable that should be considered when analyzing the surrounding area's impact on BSS (Rixey, 2013).

3.1.6. Supermarkets

The literature supports the premise that supermarkets and other retail businesses impact BBS's stations located in the same areas (El-Assi et al., 2017). The research states the existence of a correlation between proximity to supermarkets and the number of trips, and this is evidenced by the fact that users will most likely choose a BSS station closer to supermarkets and other retail businesses rather than one far away from this POI (Faghih-Imani & Eluru, 2015; Gebhart & Noland, 2014; Noland, Smart, & Guo, 2016; Tran et al., 2015; X. Wang et al., 2016).

3.1.7. Street Lights

Street lights are directly linked with safety, especially for females. The literature points to the fact that the city's luminosity can increase security; It raises each individual personal safety while also reducing the number of vehicle accidents involving pedestrians and bicycles (Krull, 2018). Furthermore, the literature points to a correlation between street lights and higher bicycle activity (Chen, Liu, & Sun, 2018). The proximity of BSS's station to street lights can be linked to an increase in bicycle pick-ups and turn-ins that may point to the user's choice of safer surroundings (Sun, Chen, & Jiao, 2018). For this reason, the impact street lights have on BSS's station should be studied.

3.2. CASE STUDY AND DATA COLLECTION

Seattle is the fifteenth largest city in the United States and the capital city for the state of Washington, with a population of seven hundred thirty-seven thousand fifteen as of 2020 - the year in which the last censuses were conducted. Roughly 50% of the Seattle population is female, and over 86% are over 18 (Government of Seattle, 2020). A 2013 survey conducted by the Seattle Department of Transportation stated that half (50%) of the Seattle residents confirm having access to a working bicycle; however, only 19% affirm using the bicycle regularly (Seattle department of transportation, 2013).

Nevertheless, Seattle is ranked the fifth bike-friendliest city in a study conducted by Bicycling Magazine in partnership with associations and organizations like People for Bikes, the Alliance for Biking & Walking, and the League of American Bicyclists. Using census and department of transportation data, this organization discovered and ranked the best bike-friendly cities in the United States. The ranking considers a variety of indicators such as bike lanes length, percentage of female cycling commuters – this indicator helps understand the perception of the safety of the bike infrastructure – and the total amount of cyclist-friendly establishments (Dille, 2016).

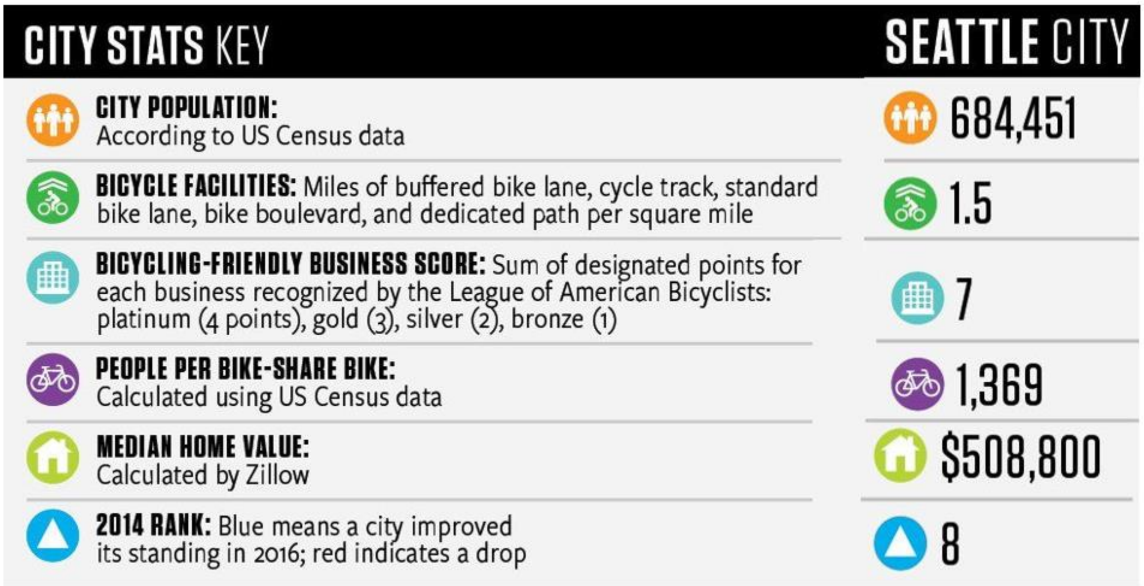

Figure 2 - Bicycling Magazine Cycling Stats (Dille, 2016)

The Pronto Cycle Share belongs to the Seattle Department of Transportation and accounts for five hundred bikes and 60 different stations. The Pronto BSS had two different types of memberships, annual membership or short-term membership that could be subcategorized into a 24-hour passe or a 3-day passe. Pronto was the first BSS program in the United States where helmets were applied to users of all ages. From October 2014 to March 2017, Pronto Cycle Share was the bike share system registering 275,091 trips. The Pronto system was set up in Downtown, South Lake Union, Belltown, Capitol Hill, the U-District, Eastlake, First Hill, Pioneer Square, and the International District.

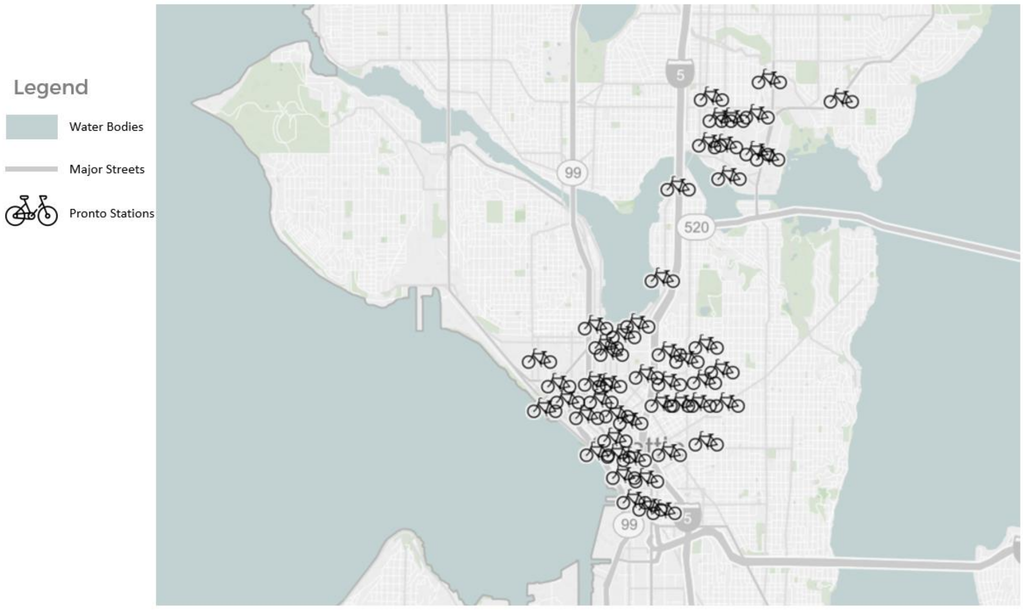

Figure 3 - Pronto Stations in Seattle

3.2.1. Data Sources

The collection data process is an essential part of any study. Keeping in mind the objective of understanding how the built environment influences trip activity patterns in the Seattle bike-sharing system for men and women reinforced the notion that the amount and quality of the data collected were of great importance. Multiple data sources were considered to gather the information needed to conduct the study.

The Seattle Open Data website provided the data on the stations' locations and the information about each trip. The Seattle Open Data website supplied the trip dataset, which accounted for information on every trip from the day of activity until the end of the program. Various data sources were considered to construct the research dataset about the built environment - bicycle infrastructure, public transport stations, and land characteristics.

The data sources are listed in Table 2, and each is mentioned in detail below.

Dataset	Contributor	Source
Pronto Cycle Share – Stations	Seattle Open Data	https://data.seattle.gov/Community/Pronto-Cycle-Share-Station-Data/ndkc-bve9
Pronto Cycle Share – Trip Data	Seattle Open Data	https://data.seattle.gov/Community/Pronto-Cycle-Share-Trip-Data/tw7j-dfaw
Bike Lanes	Seattle GeoData	https://data-seattlecitygis.opendata.arcgis.com/datasets/existing-bike-facilities

Streetcar Stations	Seattle GeoData	https://data-seattlecitygis.opendata.arcgis.com/datasets/streetcar-stations
Bus Stops and Stations in Seattle	My Geodata Cloud	https://mygeodata.cloud/data/download/osm/bus-stops-and-stations/united-states-of-america--washington/king-county/seattle
Restaurants	Seattle GeoData	https://data-seattlecitygis.opendata.arcgis.com/datasets/restaurants
Bars	GoogleMaps	G Map Extractor [1]
Private Schools	Seattle GeoData	https://data-seattlecitygis.opendata.arcgis.com/datasets/private-schools-2
Public Schools	Seattle GeoData	https://data-seattlecitygis.opendata.arcgis.com/datasets/public-schools
Libraries	Seattle GeoData	https://data-seattlecitygis.opendata.arcgis.com/datasets/seattle-public-libraries
Universities	GoogleMaps	G Map Extractor
Green Spaces	Seattle GeoData	https://data-seattlecitygis.opendata.arcgis.com/datasets/seattle-parks
Supermarkets	GoogleMaps	G Map Extractor
StreetLighht	Mapillary	https://blog.mapillary.com/

Table 2 - Data sources

The Pronto Cycle Share Station dataset (Table 3) includes information about stations: station identification, station designation, installation date, station dock count, modification date, current dock count, decommission date, location X, and location Y. This data was collected for 60 different bike stations.

Column Name	**Data Type**	**Description**
station_id	Plain Text	Station identification
name	Plain Text	Designation designation
install_date	Date & Time	Installation date
install_dockcount	Number	Station dock count
modification_date	Date & Time	Modification date
current_dockcount	Number	Station dock count
decommission_date	Date & Time	Decommission date
location X	Decimal	Longitude

[1] G Map Extractor – Web scraping tool that helps extract data from google maps search result pages and into Microsoft Excel spreadsheet (https://chrome.google.com/webstore/detail/g-map-extractor/eehgalnhbmkfalhdjkeenggnniebdpgi?hl=en)

location Y	Decimal	Latitude

Table 3 - Seattle BSS station data schema

The Pronto Cycle Share Trip Dataset (Table 4) includes information about the trip, origin and destination stations, start time and end time of trips, duration of the trip, and information about the user. The user information consists of user type (differentiating the user from a customer with an annual membership pass or a temporary pass), gender, and birth year. Additionally, the stations' name is also provided in this dataset.

Column Name	Data Type	Description
trip_id	Number	Trip identification
starttime	Date & Time	Data and hour beginning of the trip
stoptime	Date & Time	Data and hour ending of the trip
bikeid	Plain Text	Bike identification
tripduration	Number	Trip duration in seconds
from_station_name	Plain Text	Name of the destination station
to_station_name	Plain Text	Name of the departure station
from_station_id	Plain Text	Id of the departure station
to_station_id	Plain Text	Id of the departure station
usertype	Plain Text	Member pass or a temporary pass
gender	Plain Text	Gender of the user
birthyear	Plain Text	Year of birth of the user

Table 4 - Seattle BSS Trip data schema

3.2.2. QGIS

The program chosen for the development of the Seattle map was QGIS. The choice is based on the fact that QGIS is a geographic information systems (GIS) program, free to use, with open source code and an intuitive interface.

All the data sources were uploaded to the program, and with the QGIS OpenStreetMap Plugin, a vector data layer was added to outline the city. This software accomplished all the conditions required to create the built environment and land characteristics.

To study the influence the spatial variables have on each gender's mobility pattern, the distance from each station to the POI, regarded as an influencer factor to mobility, was measured. Thus, to examine the influence the various POI has on bicycle arrival and departure values, a 500 meters buffer was created to capture the spatial characteristics of each bike share station. While it is possible to explore several distance thresholds, some scholars considered, when doing the same study, a radius of 250 meters (Faghih-Imani et al., 2014). However, a significant part of the literature believes walkable distances go up to 500 meters (Faghih-Imani & Eluru, 2016; K. Wang & Akar, 2019), thus justifying the choice. Therefore, all the POI found outside each station's 500 meters radius were not considered.

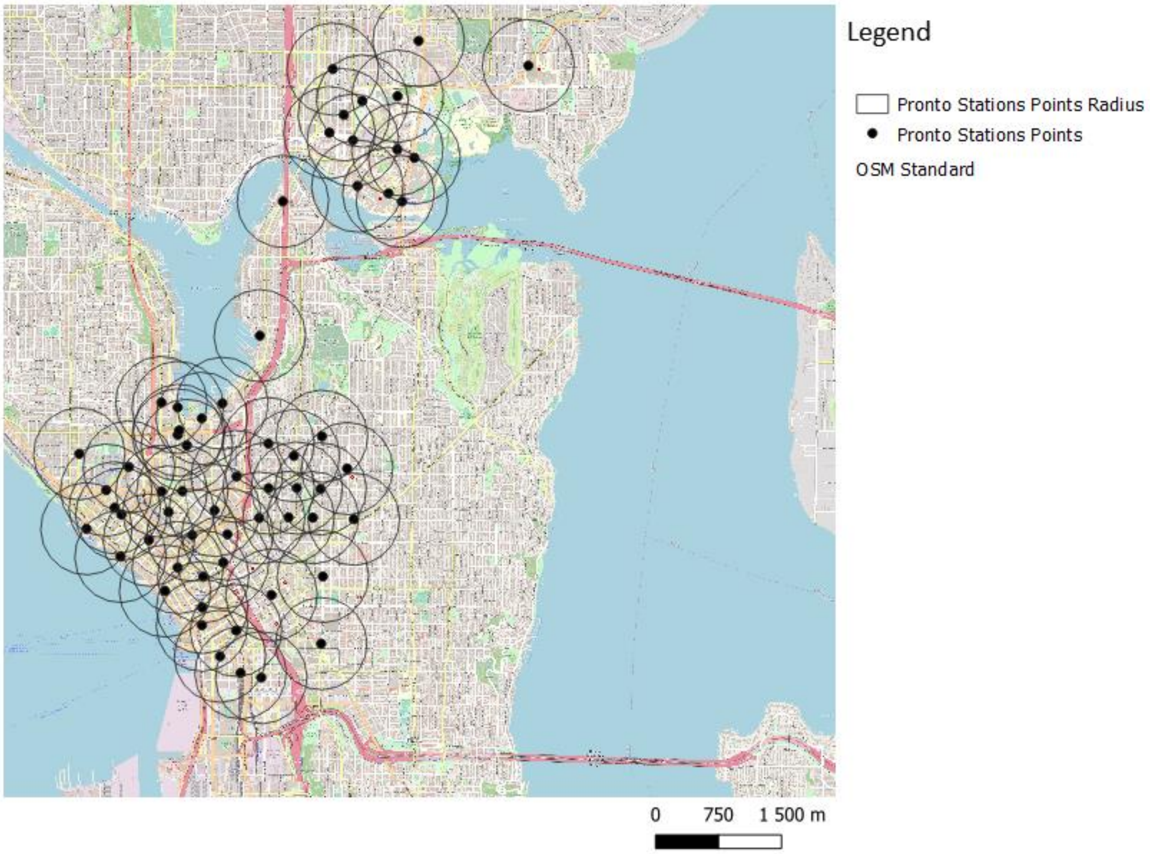

Figure 4 - Bikeshare stations with calculated service areas of 500 meters radius

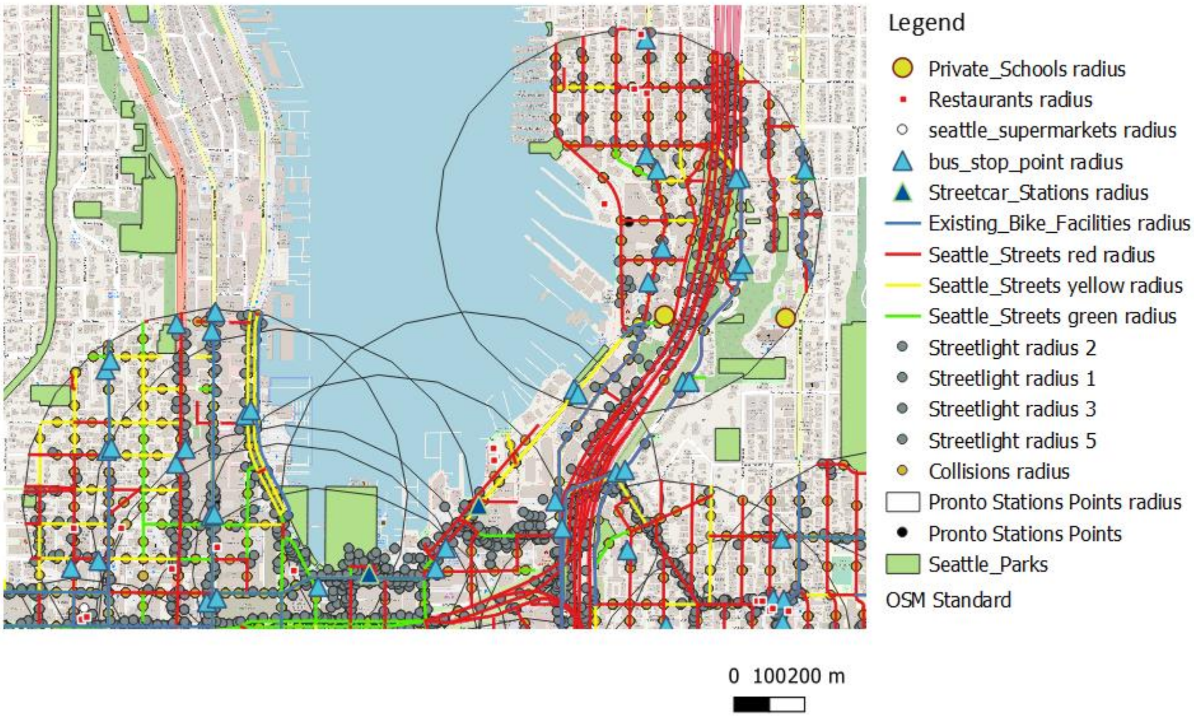

Figure 5 - Bikeshare station POI inside radius

3.3. Sample Characteristics

The descriptive summary of sample characteristics is presented in Table 5.

Variable	Mean	Std. Deviation	Max	Min
Bikes Lanes	45.92	24.74	97	3
Restaurants	32.18	20.36	76	0
Bars	4.03	5.22	22	0
BUS	27.20	13.53	68	4
Streetcar	1.70	2.04	6	0
University	2.02	2.34	14	0
Public School	0.15	0.36	1	0
Private School	0.57	0.87	3	0
Libraries	0.39	0.67	2	0
Super	1.44	1.59	7	0
Parks	4.70	2.39	11	1
Street Lights	1546.39	1001.68	4441	153

Table 5 - Descriptive summary of sample characteristics

3.4. Multiple Linear Regression

The bivariate regression model is the most common methodology employed to study continuous dependent variables such as arrival and departure. The analysis shows the influence all independent variables have on the dependent variable. Taking into account the multitude of variables under study and the number of observations, the literature supports using the multiple linear models (Faghih-Imani et al., 2014; Rixey, 2013).

The statistical method that studies and analyzes the relationship between continuous (quantitative) variables is called a Multiple Linear Regression. The relationship between the variables can be explained by separating the variables into two categories. One category is the predictor, independent or explanatory variable (X), and the other category is the outcome, dependent, or response variable (Y). The Multiple Linear Regression differs from the singular linear regression by having multiple independent variables. The goal of the model is to find the best fitting line that explains the relationship and effect each of the explanatory variables has on the response variable.

The following equation then expresses multiple linear regression:

$$\gamma = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_k x_k + e$$

The formula has the following structure, y denotes the dependent variable, X={x1, x2,…,xk} is a vector composed of all the independent variables. The β's are the parameters responsible for adjusting the weight of each variable, and β0 does not have any variable associated and reflects the interception with the Y-axis. The "e" is the sum of all the errors between the predicted values concerning the observed values. Let k= 1, 2, …, K be an index to represent each variable.

3.4.1. Assumptions

An essential part of running any statistical model is the assumption test. That is the case with multiple linear regression. The validity of the results depends on the fact that the assumptions about the relationship between the explanatory variable (X) and the response variable (Y) are met (Hays, 1983; Poole & O'Farrell, 1971). The decision to consider a multiple linear regression must be accompanied by the confirmation that the data meets all the assumptions; otherwise, the model may end up with unreliable results.

The five assumptions are (1) Linear relationship; (2) No Multicollinearity; (3) Independence; (4) Homoscedasticity; (5) Multivariate Normality (Field, 2018), as presented below.

1. **Linear relationship**

The first assumption of multiple linear regression states that the predictors and the target variable must follow a linear relationship. Furthermore, it is highly recommended that a test for outliers is performed because the existence of outliers may influence the linearity of the model. The easiest way to test this assumption is to create a scatter plot of each predictor variable and the response variable. This assumption can be tested by drawing a scatter plot with all the data points between the predictors and the target variable. If the points in the scatter plot displayed a straight diagonal line, then there is reason to believe that a linear relationship between the variables subsists. If this assumption is violated, nonlinear transformation to the predictor variable must be considered.

2. **No Multicollinearity**

The second assumption of multiple linear regression states that there is no correlation between the predictor variables. Two variables are considered correlated with each other, if the change in one affects the other. This assumption allows for assessing the redundancy of each variable. If they are perfectly correlated, then both variables contain the same information, which means only one is necessary. When the regression model suffers from multicollinearity due to correlation between one or more independent variables, the coefficient estimates in the model become unreliable. The correlation matrix, the Variance Inflation Factor (VIF), and the tolerance must be calculated to test this assumption. The conditions that confirm that the independent variable does not have Multicollinearity is that VIF must be less than 10 (Field, 2018). The correlation matrix coefficients whose magnitude is above 0.8 must be considered variables highly correlated (Field, 2018). If this assumption is violated and one or more predictor variables are considered correlated, resolving this issue is simply removing those predictor variables.

3. **Independence**

Verifying if the values of residuals do not exhibit autocorrelation is the test done to confirm the assumption of multiple linear regression that observes if the dataset is independent. The execution of a Durbin-Watson test is undertaken to determine if the assumption is met. Durbin-Watson is a formal statistical test that affirms whether or not the residuals and the observations exhibit autocorrelation. The Durbin-Watson test concludes that if the d value - test statistic for the Durbin-Watson - is higher than 1.5 but lower than 2.5, the autocorrelation is deemed within bounds (Field, 2018). When this assumption is violated, there is evidence of positive correlation, and the addition of lags in the variables must be considered.

4. **Homoscedasticity**

The fourth assumption of multiple linear regression states that the errors or the noise must have similar variances across all levels of the predictor variable. Essentially, the model must strive for a scenario where the spread of residuals should have constant variance or at least minor fluctuations along with any predictor variable. When variances are unequal, the residuals are said to suffer from heteroscedasticity. The violation of this assumption invalidates the confidence intervals and significance tests. For this reason, when this assumption is violated, heteroscedasticity must be fixed. The most common ways of fixing heteroscedasticity are transforming the response variable, redefining the response variable, or using weighted regression.

5. **Multivariate Normality**

Finally, this last assumption of multiple linear regression states that the errors are normally distributed. Normally distributed error means that the differences between the predicted and observed data are zero or very close to it. It is essential to distinguish this assumption from the idea that the predictors have to be normally distributed, which they do not. This assumption, alongside the homoscedasticity and Independence assumption, results in errors being iid. $N(0, \sigma^2)$. The most common ways to check if this assumption is met are to create a Q-Q Plot or conduct a formal statistical test like Shapiro-Wilk, Kolmogorov-Smirnov, Jarque-Barre, or D'Agostino-Pearson. The most used approach is the Q-Q plot, which determines if a model's residuals follow a normal distribution by confirming that the plot roughly forms a straight diagonal line. If this assumption is violated, firstly, the existence of extreme outliers must be verified. If the assumption is still violated, then a nonlinear transformation to the response variable must be considered.

3.4.2. Significance Testing

An essential part of studying multiple independent variables is the significance test of those variables because this is the only way to confirm that a variable brings value to the model. The confirmation of the importance of a specific variable for the model is achieved by conducting a hypothesis test. A significance-based hypothesis test is composed of two hypotheses; The null hypothesis (H0), which states that there is no significant difference between each coefficient, and the alternative (H1) that directly contradicts the H0 (Gareth James, Daniela Witten, Trevor Hastie, 2015). Therefore, the hypotheses test is presented in the following manner:

$$\begin{cases} H_0: \beta_k = 0 \\ H_1: \beta_k \neq 0 \end{cases}$$

A coefficient of 0 indicates that any change in the independent variable will not alter the dependent value. On the contrary, if a variable has a coefficient-value different from zero, there is reason to believe that the variable significantly predicts the outcome.

This hypothesis is tested using a t-statistic test. Conducting the test will allow discovering the p-value for each variable, this will indicate whether the predictor is statistically significant. If the test is significant, which means that the p-value is lower than α - defined at $\alpha=0.05$ – then there is statistical evidence supporting the rejection of the null hypothesis. The rejection of the null hypothesis concludes that the coefficient value is significantly different from 0, which can be resumed as the independent variable contributes significantly to the model's outcome. However, if the p-value is greater than 0.05, $\alpha=0.05$, then there is no significant evidence to reject the null hypothesis. If this happens, the conclusion is that there is no correlation between the predictor and response variable (Figueiredo, 2020).

However, determining which explanatory variable significantly contributes to the model is not enough to assess the accuracy of a model across different samples. Cross-validation must be performed to assess how well the model might predict the outcome of other samples. Cross-validation is the process of analyzing if the model can accurately predict the same outcome variable when the same set of predictor variables are at stake. One of the principal cross-validation methods in multiple linear regression is the Adjusted R^2 (Santos, 2015).

R^2 or Coefficient of Determination is a crucial output of the regression analysis. The value of the coefficient of determination measures the accuracy of the prediction of the model's dependent variable. This coefficient presents the proportion of variance explained by the explanatory variable for the response variable (Rencher & Schaalje, 2008).

The Adjusted R^2 is recommended for Multiple Linear Regression because adding features to the model will decrease Adjusted R^2 if the features chosen are irrelevant to the model. For this reason, the Adjusted R^2 is the coefficient chosen to quantify the model's explanatory power. Similar to R^2, Adjusted R^2 is the proportion of the variation in variable Y that is explained by the regression equation when the predictors' variables $X\mathrm{k}$ are involved. In other words, Adjusted R^2 tells how much the variance in the outcome would be accounted for if the model had been derived from the population from which the sample was taken (Field, 2018). As already mentioned, the Adjusted R^2 is a proportion, with values between zero and one, $0 \leq$ Adjusted $R^2 \leq 1$.

3.4.3. Analysis of Variance

The analysis of variance (ANOVA) is, mathematically speaking, a variant of the linear regression where the independent variables are categorical. So, just like the regression model, it will provide knowledge about the levels of variability within the model (Field, 2018). Precisely like the significant test performed on each variable and coefficient of determination results, it is also possible to determine the model's viability with the analysis of variance. ANOVA tells if the model can significantly predict the dependent variable's outcome. For that reason, the ANOVA is one of the most popular ways to analyze the model's fit to the data (Field, 2018).

The most relevant part of the ANOVA table is the F-statistic test. Like the significant test performed on each variable, the null hypothesis indicates that the model is not significant; the goal is to reject H0 in favor of the H1 – significant model. The column labeled F gives the F-statistic in the ANOVA table, and the column labeled Sig. presents the p-value. H0 is rejected – the model significantly predicts the dependent variable's outcome – when the p-value is lower than 5%. Therefore, the conclusion reached is that the model can significantly predict the results of the variable under study (Field, 2018).

4. RESULTS

This chapter will present the thesis results. The results from section 4.1 are the outcome of analyzing the Pronto Cycle Share Trip dataset data. This independent analysis allowed for a descriptive analysis of the trips, always maintaining in mind the gender differentiation. Section 4.2 shows the regression model results analyzed according to the already defined variables.

4.1. BIKE USAGE ANALYSIS

In what concerns the users' distribution, it is verified that 173815 (63.18%) of the existing trips were conducted by registered members – for this type of user, information like gender and age is available. Non-registered members made the remaining 101276 (36.82%) trips, so these users have no gender categorization (see Fig.5.). As the analysis intends to understand the different utilization patterns of each gender, only the data provided by registered members will be considered, 63.18% of the total amount of trips, resulting in a new sample of 173815 trips.

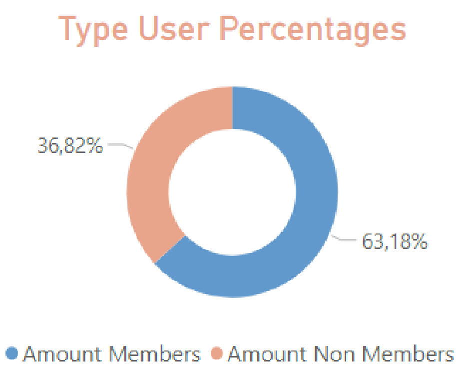

Figure 6 - Type of User Percentage / Types of User by Year

Regarding gender usage, men conducted 79.43% of the trips on average in the period in question. The distribution for each year follows the average. However, 2017 shows that 84% of the total number of trips was led by males, five times more than the total number of female trips (Fig.7).

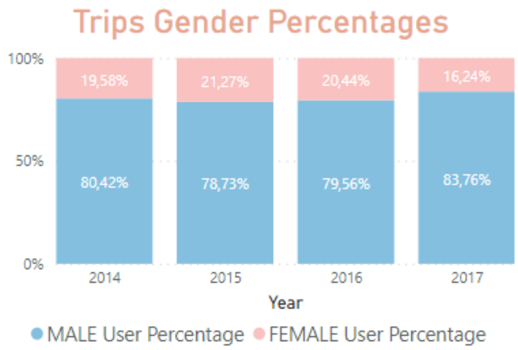

Figure 7 - Members' Trips By Gender

To better understand the gender difference in BSS use, besides the total amount of trips, the duration and distance of the trips were also explored.

The Summer months (June, July, August) and October and November were registered as the month with more trips for men. The female users of Pronto seem more consistent in their use of BSS, showing less fluctuation in their use; however, the month of May registered the highest values of female usage, as depicted in Fig. 7.

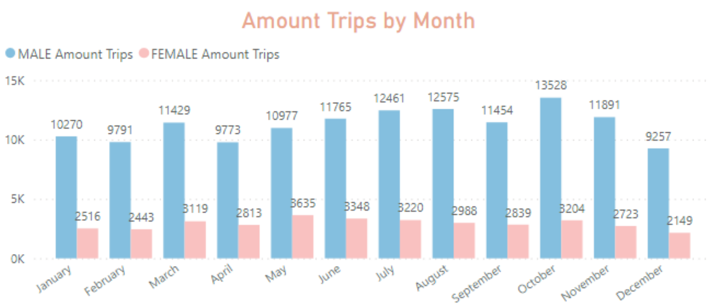

Figure 8 - Total Trips by Month

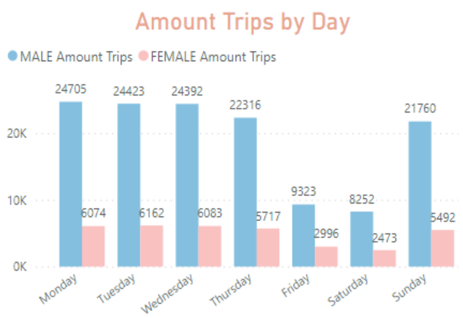

Figure 9 - Total Trips by WeekDay

The week analysis shows significantly fewer entries for Friday and Saturday for both genders. However, the male user difference between the remaining days of the week and Friday and Saturday is much more pronounced, with a reduction of 58.2% of the total amount of trips. Although the female user appears to also use BSS significantly less often on Friday and Saturday - a decrease of 47.6% - the difference in the total number of trips between the remaining days of the week is much smaller than the one presented by their male counterpart (see Fig.8.). Monday through Thursday, the weekday usage is remarkably consistent for both genders.

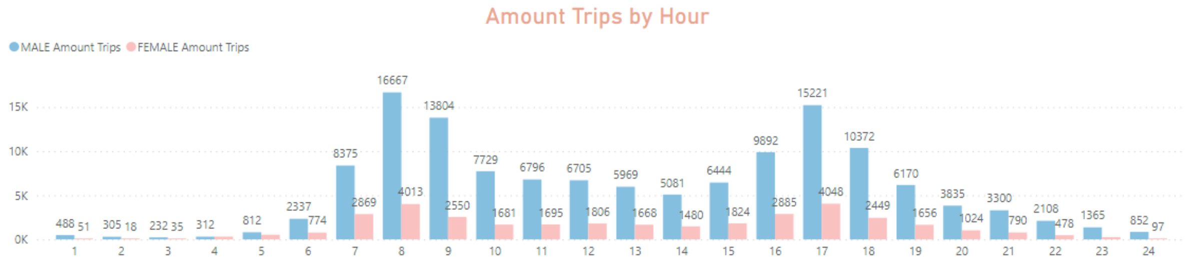

Figure 10 - Total Trips By Hour

The distribution of bike use by the hour of the day was also conducted. The higher usage rate corresponds to 8h, followed by 17h and 9h (see Fig. 9), which makes sense since it is the usual start and end of the work day - rush hour. There is also a high usage rate at 7h, and 18h. Also, it is possible to see that the citizens start to use this service at 6h to 23h, having no significant usage between 24h and 5h (see Fig. 9). However, women's hour rate analysis shows that between the hours of 21h and 5h, the number of women using BSS is nearly non-existent (see Fig. 9).

The duration of the trips was also analyzed, and on this indicator, women take the lead. On average, women's trip duration is superior to men's. The higher usage rate corresponds to an average of more than three minutes duration per trip. This analysis was made at year, month, week, and day levels.

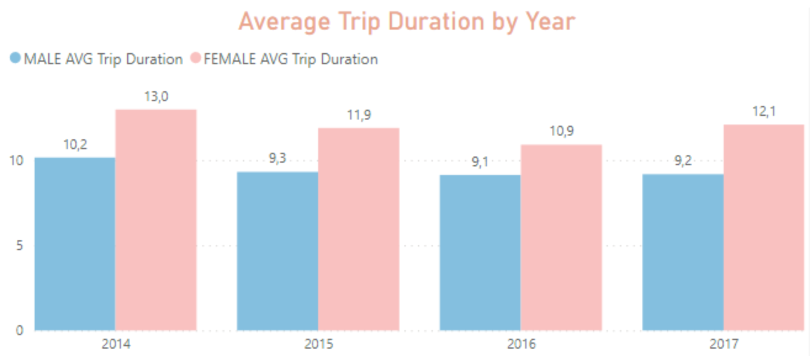

Figure 11 - Trip Duration By Year

For both genders, 2014 was when the average duration of the trips was longer in both cases; however, men seem to have stabilized the duration while women have a more significant difference in duration each year (see Fig. 10).

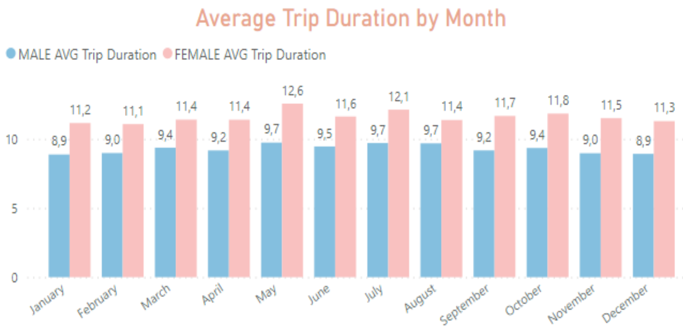

Figure 12 - Trip Duration by Month

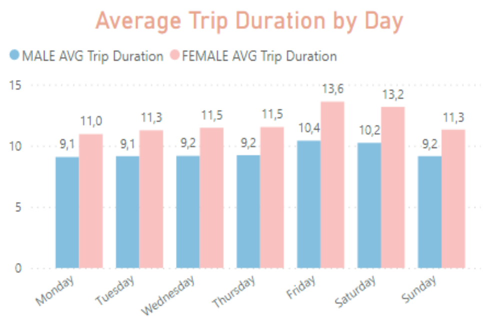

Figure 13 - Trip Duration By Weekday

The distribution by month shows that men do not present a difference in duration throughout the year while women have May as the month with the more extended trip and February with the shortest trip, on average (Fig.11).

The week analysis shows that disregarding the outliers (Friday and Saturday), the average duration of trips for each gender is relatively consistent. Both genders seem to have a slower pace on Friday and Saturday since they register higher duration values (Fig.12).

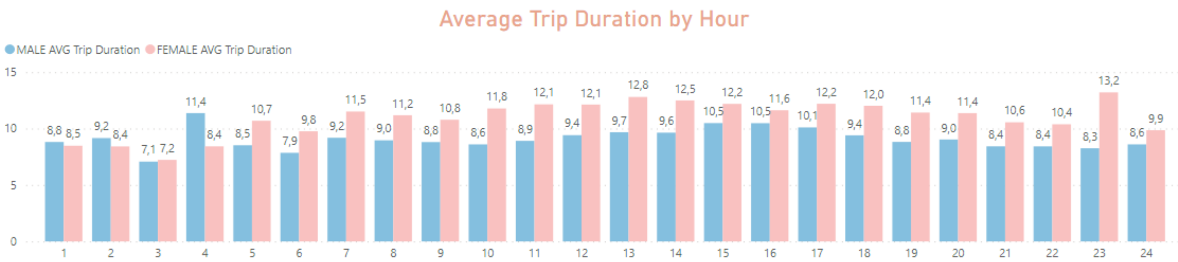

Figure 14 - Trip Duration by Hour

The distribution by the hour of the day concluded that between 10h and 17h the duration of the trips is slightly higher for both genders. However, women have the most extended duration registration at 23h while men have it at 4h (Fig. 13).

Furthermore, from all the different time analyses, it is possible to see that women take longer trips than men. When comparing the number of trips by the hour and the duration of said trips in the same period, the conclusion arrived shows that the time of the day with the higher number of trips is also the period with the shorts trips – time-wise. During rush hour, both genders appear to conduct their bicycle trips at a faster pace.

The reason women have a longer journey duration can be caused by women traveling greater distances or at a slower speed. To answer this matter, the analysis of the distance between the stations must also be considered.

The distance between stations was not part of the original data sample, which raised the need to compute a distance matrix. Since the location of each station was known, the computation of the matrix was accomplished via QGIS. The distance is measured based on a Voronoi diagram (Kim, 2021), which means that the distance between stations was computed as a linear distance. After having the calculated distance for every station pair, the values were updated to the station data set to extract relevant metrics between the run-through distance differences for each gender. Important to state that the distance of the trips that started and ended in the same docking station could not be computed since there is no way of determining the path run-through by the user.

The descriptive summary of distance matrix characteristics is presented in Table 6.

Max	Min	Mean	Median
7947.981	54.669	2804.568	2178.084

Table 6 - Descriptive summary of distance matrix characteristics (in meters)

Therefore, regarding the distance analyses by gender, women travel longer distances than men on average. On average, females' distance is 1497 meters while men's average is around 1379 meters per trip. This analysis was made at year, month, week, and day levels like the duration analysis.

Women present a higher average distance run through in all years except 2017, where both genders seem to have a difference of merely 3 meters (see Fig. 14).

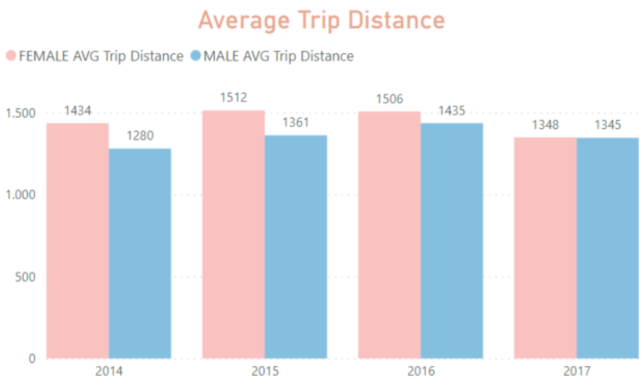

Figure 15 - Trip Distance by Year

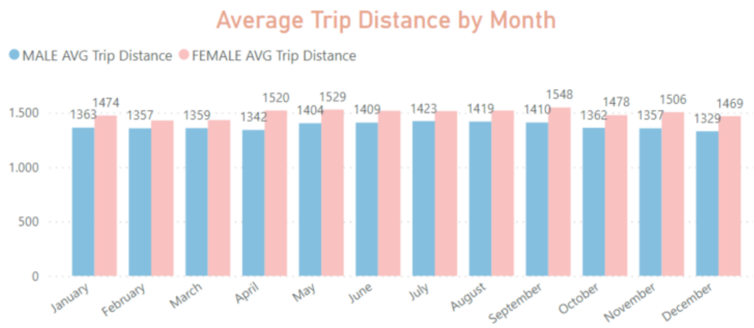

Figure 16 - Trip Distance by Month

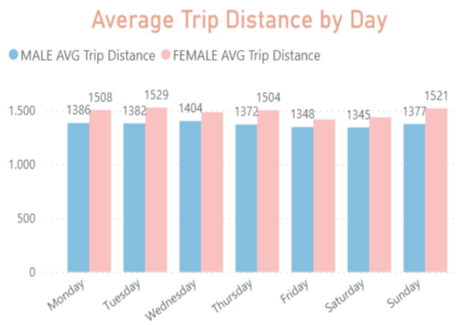

Figure 17 - Trip Distance by Day

The monthly distribution shows that the Pronto users do not show a difference in length throughout the year, both genders being relatively consistent (Fig.15).

The week analysis shows that Friday and Saturday are for women, the days of the week where the average distance of each trip is smaller. Men seem to have an equal distance run-through all day of the week. (Fig.12).

The distribution by the hour of the day concluded that for both genders, the highest distance run-through is conducted by men at 4h in the morning. The early hours of the day, from 1h to 4h, are the hours where men have higher travel distance run-through. Excluding the 15h and 16h hours of the day where men appear to have longer distance registered, the day's remaining hours present consistency in the distance run-through, with the female user logging higher distance traveled.

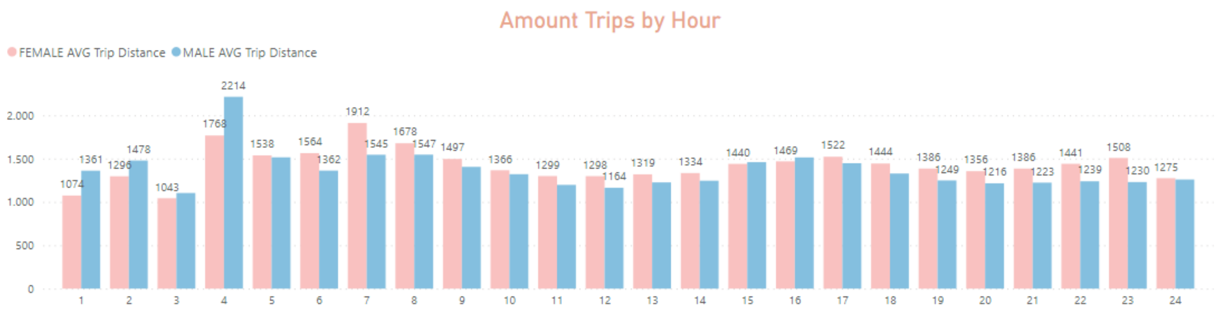

Figure 18 - Trip Distance by Hour

4.2. Built Environment

The regression model represents the relationships between the variables and the number of trips registered to understand the effects the built environment has on bike sharing usage in Seattle for each gender.

Since the dataset distinguishes between departure stations and arrival stations, the analysis was made considering the different impacts the built environment has on departures and arrival stations for each gender.

Table 6 shows the Coefficient of Determination (R^2) of each model.

Model	R	R^2	Adjusted R^2	Std. Error of the Estimate
Male Departure	0.680	0.463	0.319	1334.87349
Female Departure	0.745	0.554	0.424	288.21517
Male Arrival	0.678	0.459	0.315	1316.13178
Female Arrival	0.461	0.212	0.002	367.82354

Table 7 - Model Summary

The adjusted coefficient of determination indicates the measures of the proportion of variability for the model. Thus, as seen in Table 2, 31.9% for the Male Departure, 42.4% for Female Departure, 31.5% for Male Arrival, and 0.2% for Female Arrival are accounted for by the independent variables included in the model. So, it is possible to affirm that the models explain the variability of the dependent variable - global satisfaction of the subjects in the sample – with values of 31.9%, 42.4%, 31.5%, and 0.2%, respectively.

However, it is not enough to analyze the adjusted coefficient of determination. The result obtained from the analysis of variance - ANOVA – will indicate if it is possible to reject H0 in favor of H1, which will indicate if the model is significant. Table 7 presents for each model the ANOVA values obtained.

Model		Sum of Squares	df	Mean Square	F	Sig.
Male Departure	Regression	69041232.675	12	5753436.056	3.229	0.002
	Residual	80184925.325	45	1781887.229		
	Total	149226158.00	57			
Female Departure	Regression	4237876.852	12	353156.404	4.251	<0.001
	Residual	3405787.241	41	83067.981		
	Total	7643664.093	53			
Male Arrival	Regression	70746518.519	12	5895543.210	3.182	0.02
	Residual	83370587.912	45	1852679.731		

	Total	154117106.43	57			
Female Arrival	Regression	1639012.333	12	136584.361	1.010	0.456
	Residual	6088237.184	45	135294.160		
	Total	7727249.517	57			

Table 8 - ANOVA

As stated, the test will be conducted with a defined α of 0.05. All P-values under the value of α will have enough statistical evidence to support the rejection of the null hypothesis. Male Departure with a P-value of 0.002 is statistically significant; Female Departure with a P-value inferior to 0.001 is statistically significant; Male Arrival with a P-value of 0.02 is statistically significant; Female Departure with a P-value of 0.456 is not statistically significant. There is no statistical evidence supporting that the dependent variable Female Arrival, can be explained by the independent variables included in the model.

The coefficient must be analyzed to understand the built environment's impact on the model entirely. The slope of each coefficient determines the effect each variable will have on the dependent variable. The tables below exhibit each model's estimated coefficients and their significance levels.

Departure	Male					Female				
	Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta			B	Std. Error	Beta		
(Constante)	152.543	657.133		0.232	0.817	274.969	142.426		1.931	0.06
Bikes Lanes	23.561	17.843	0.366	1.32	0.193	10.97	4.01	0.755	2.736	**0.009**
Restaurants	-44.811	19.477	-0.56	-2.301	**0.026**	-15.571	4.294	-0.863	-3.626	**0.001**
Bars	-162.964	90.881	-0.534	-1.793	0.08	-42.86	20.141	-0.592	-2.128	**0.039**
BUS	-0.397	31.422	-0.003	-0.013	0.99	-11.941	7.185	-0.436	-1.662	0.104
Streetcar	-77.038	120.325	-0.096	-0.64	0.525	-81.182	26.369	-0.447	-3.079	**0.004**
Uni	-13.24	98.24	-0.019	-0.135	0.893	-23.195	21.312	-0.147	-1.088	0.283
Public School	1450.939	606.927	0.312	2.391	**0.021**	94.906	143.85	0.079	0.66	0.513
Private School	1253.433	331.853	0.681	3.777	**<0.001**	322.905	77.496	0.75	4.167	**0**
Libraries	-467.381	377.411	-0.195	-1.238	0.222	-235.087	89.494	-0.425	-2.627	**0.012**
Super	557.323	243.872	0.556	2.285	**0.027**	119.167	54.31	0.49	2.194	**0.034**
Parks	64.607	114.456	0.095	0.564	0.575	71.573	25.211	0.456	2.839	**0.007**
Street Lights	0.922	0.409	0.585	2.254	**0.029**	0.211	0.09	0.585	2.355	**0.023**

Table 9 – Coefficients of Departure Model

Male

Restaurants (β=-0.560, P-value < 0.05), public schools (β=0.312, P-value < 0.05), private schools (β=0.681, P-value < 0.05), supermarkets (β=0.556, P-value < 0.05) and street lights (β=0.585, P-value < 0.05) are the built environment elements that significantly influence, for men, the adhesion of BSS on the departure station.

Female

Bike lanes (β=0.755, P-value < 0.05), restaurants (β=-0.863, P-value < 0.05), bars (β=-0.592, P-value < 0.05), streetcars (β=-0.447, P-value < 0.05), private schools (β=0.750, P-value < 0.05), libraries (β=-0.425, P-value < 0.05), supermarkets (β=0.490, P-value < 0.05), parks (β=0.456, P-value < 0.05) and street lights (β=0.585, P-value < 0.05) are the built environment elements that significantly influence, for women, the adhesion of BSS on the departure station.

Arrival	Male					Female				
	Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta			B	Std. Error	Beta		
(Constante)	1378.378	673.478		2.047	**0.047**	472.416	183.675		2.572	**0.013**
Bikes Lanes	37.609	18.022	0.575	2.087	**0.043**	3.335	4.848	0.224	0.688	0.495
Restaurants	-22.278	19.104	-0.28	-1.166	0.25	-0.386	5.267	-0.021	-0.073	0.942
Bars	46.403	93.13	0.15	0.498	0.621	-0.327	25.091	-0.005	-0.013	0.99
BUS	-42.66	32.007	-0.353	-1.333	0.189	-10.277	8.593	-0.38	-1.196	0.238
Streetcar	-137.123	125.678	-0.159	-1.091	0.281	-25.746	33.566	-0.136	-0.767	0.447
Uni	-118.343	100.278	-0.172	-1.18	0.244	-27.884	27.264	-0.179	-1.023	0.312
Public School	37.968	602.329	0.008	0.063	0.95	3.378	164.038	0.003	0.021	0.984
Private School	1029.623	335.637	0.539	3.068	**0.004**	153.087	99.704	0.35	1.535	0.132
Libraries	-311.614	397.574	-0.122	-0.784	0.437	-116.034	109.951	-0.203	-1.055	0.297
Super	-180.783	241.144	-0.177	-0.75	0.457	-28.33	65.16	-0.123	-0.435	0.666
Parks	-133.811	113.936	-0.196	-1.174	0.246	-4.139	30.91	-0.027	-0.134	0.894
Street Lights	1.019	0.415	0.634	2.458	0.018	0.211	0.11	0.58	1.92	0.061

Table 10 - Coefficient Arrival Model

Male

Bike lanes (β=0.575, P-value < 0.05), restaurants (β=-0.280, P-value < 0.05), private schools (β=0.539, P-value < 0.05) and street lights (β=0.634, P-value < 0.05) are the built environment elements that significantly influence, for men, the adhesion of BSS on the arrival station.

Female

There are no built environment elements that significantly influence, for women, the adhesion of BSS on the arrival station. There is no statistical evidence supporting that the dependent variable Female Arrival, can be explained by the independent variables included in the model.

Bike lanes, restaurants, bars, streetcar stations, public schools, private schools, libraries, supermarkets, parks, and street lights are the built environment elements that significantly influence the overall satisfaction of the models. However, this does not mean that the other variables do not affect both men's and women's departure and arrival rates; it only means that they are not statistically significant in this specific model with this sample data.

4.2.1. Assumption Testing

To guarantee the feasibility of the results the model's assumptions must be tested. As mentioned in Section 3.4.1, the five assumptions that must be met are linear relationship, multicollinearity, independence, homoscedasticity, and multivariate normality.

The liner relationship assumption is tested by drawing a scatter plot with the data points between the predictors and the target variable. Appendix A – Section 9.1.1 shows that all the scatter plots follow a linear relationship; therefore, the assumption is met.

Multicollinearity assumption is tested by analyzing VIF (Variance Inflation Factor). The results presented in Table 13 show that all the VIF values are significantly lower than ten. In other words, there is no multicollinearity - the assumption is confirmed.

	Male Departure	Female Departure	Male Arrival	Female Arrival
Bikes Lanes	6.44808	7.004293	6.310669	6.075197
Restaurants	4.953757	5.217742	4.79212	4.84191
Bars	7.436142	7.123855	7.584569	7.464922
BUS	5.897109	6.319431	5.83642	5.760959
Streetcar	1.89399	1.937824	1.760351	1.797745
Uni	1.722357	1.672769	1.758568	1.757781
Public School	1.42569	1.328579	1.488944	1.512237
Private School	2.723603	2.978936	2.567443	2.970729
Libraries	2.083885	2.414011	2.018183	2.113715
Super	4.951257	4.58971	4.65882	4.596992
Parks	2.384049	2.376495	2.316617	2.355811
Street Lights	5.638457	5.688905	5.541374	5.212093

Table 11 - VIF Values

To test that each observation in the dataset is independent and that values of residuals do not exhibit autocorrelation, the d - test statistic for the Durbin-Watson must be analyzed. The results presented in Table 14 show that the d values for the models of Male Departure, Female Departure, and Male Arrival are within bound. In other words, the assumption is confirmed. The female model Arrival is lower than 1.5, so the assumption of independence is violated.

	Male Departure	**Female Departure**	**Male Arrival**	**Female Arrival**
Durbin-Watson	1.692	1.698	1.768	1.430

Table 12 - Durbin-Watson Values

The homoscedasticity assumption is tested by creating a plot of standardized residuals versus predicted values. As shown in Appendix A – Section 9.1.2, all the points in the scatter plot do not exhibit a pattern indicating that the residuals have constant variance at every point in the linear model, confirming that the assumption is validated.

Lastly, the last assumption must guarantee that the errors are normally distributed. The Kolmogorov-Smirnov test and the Shapiro-Wilk test were conducted. The results show for all models that the residuals are normally distributed with a significance value of 99%, confirming that the last assumption is met (Appendix B – Section 9.2).

5. DISCUSSION

This chapter intends to discuss the results presented in the previous chapter. The discussion just as the results will be analyzed separately: Section 4.1 presented the results for the bike usage analysis; Section 4.2 presented the results for the built environment impact on BSS adhesion.

5.1. SUMMARY

The results obtained show that Seattle follows the worldwide tendency regarding BSS use, with the men being the primary user (K. Wang & Akar, 2019).

The analyses of the total number of trips by each gender conclude that the results agree with the literature stating that men are the predominant user (Goodman & Cheshire, 2014), responsible for almost 80% of the total trips. Even though there is an incentive to consider women as key indicator users in this mode of transportation (Akar et al., 2013), Pronto Cycle Share saw a decrease in women's usage during their operation period. From 2015 to 2016, a decrease of 0.83%, and from 2016 to 2017, a decrease of 4.2% in female users. In contrast, there was an increase in male users.

The results presented in the month and hour analysis go according to the literature, the months with better weather as well as rush hour have higher adhesion (Gebhart & Noland, 2014; Sun et al., 2018). The weekday analysis presents exciting results. The studies that report weekends as the days with the higher decrease in usage explain this phenomenon by stating that BSS is used for commute purposes (Zhang, Pan, Li, & Yu, 2016; Zhao, Wang, & Deng, 2015; Zhou, 2015) which justifies the higher adhesion Monday through Thursday. However, the city of Seattle sees its decrease in use only on Friday and Saturday but not on Sunday. This can be explained by the fact that Friday and Saturday are the day of the week with more night activity (Sweeny & Sweeny, 2017). Because of this, the Pronto users may opt to make their journey on a mode of transportation that does not require the full use of the users' motor and coordination skills. However, the rise in adhesion on Sunday can be explained by the fact that Sunday is a day associated with leisure and family activities, leading to a higher use rate.

Regarding the duration of the trips, the sample data provided by Seattle's BSS meets the expectations of the literature. Pronto Cycle Share saw their female user have a mean trip duration superior to the male user of 2.32 minutes, concluding that women travel at a slower pace. Peters (2013) states that women tend to choose slower means of transportation more often than not. One of the cornerstones of this theory is that women's regard for safety is stronger than that of males (Ravensbergen et al., 2019).

Besides comparing the number of trips conducted and the duration of the trips, the distance between men and women was also analyzed. As seen in the previous chapter, the average distance run through by women is 1497 meters while men's 1379 meters, an average difference of 118 meters, with women being the user traveling longer distances.

The literature establishes as a differentiating characteristic of women's mobility patterns the fact that women travel a chain of short trips (shorter distances) with various reasons for each trip (Shaw et al., 2020). Keeping in mind that the female users of Pronto Cycle Share are traveling longer distances than male users raises some questions. As a way to help understand the reason behind this phenomenon, some research was conducted. Zhou (2015) and Faghih-Imani & Eluru (2015) conducted a study on Chicago's BSS, and their results also presented women as the user with the most traveled distance, their analysis points to the fact that women carry out longer trips due to the fact that there are using BSS for physical activity. However, Zhou (2015) points to the need to confirm if this pattern exists in other cities.

Considering that this pattern is also present in Seattle, the explanation that few women who use BSS are regular members who subscribe to the service to partake in physical activity is confirmed.

Based on the built environment analysis results, it is possible to affirm that of the four proposed models, three are statistically significant. The model can, with acceptable values of significance, explain that the characteristics of the environment affect the choice behind the departure and arrival stations for men and the departure stations for women. The arrival stations for women return values that on their own cannot explain the phenomenon. It is important to remember that this does not mean that these combinations of variables do not explain women's arrival station choice, only that this relationship could not be made with the sample data from Pronto Cycle Share. There is insufficient data to validate why the women's arrival model is not significant. In order to understand the impact between the variables and the station adherence, each variable will be analyzed separately.

5.1.1. Bike Lanes

These results are somewhat in agreeance with those obtained in the research. Bike lines positively affect the station's adherence for both genders. However, while the impacted model was the arrival model for men, it was the departure model for women. Moreover, this variable has a more significant impact on female riders than male riders. According to Handy (2011), Heesch et al (2012), and the National Research Council (U.S.) (2005), this was the awaited result since women cyclists tend to give more importance than men cyclists to bike paths.

5.1.2. Public Transport Services

The impact the public transport services have on BSS adhesion varies according to the type of transport. While the streetcar variable only affects women, the bus station is not significant for any model.

Wang & Akar (2019), affirm that the public transport services have a different impact on each gender. The reason behind the different effects public transport services have on men and women is that each gender uses BSS with different intentions. While streetcar stations do not appear statically significant for any male model, women's departure model is negatively impacted by this variable. This result can be explained by the fact that men are more likely to use BSS services for commuting which means that the public transit services can enhance the commute experience. While women are more often using BSS for recreational activities (Zhou, 2015), making less sense to complement these modes of transportation with each other (K. Wang & Akar, 2019).

5.1.3. Restaurants

The results obtained stated that the restaurants negatively impact the station's adherence for both genders. The impact on restaurants is only present in the departure model, with once again the female model having a more significant coefficient associated with the variable. This result is surprising since every time this variable was statistically significant in the literature was with a positive correlation to the arrival and departure rate. This may be related to going to a restaurant is an experience that people usually prefer to do with company and not alone (Bagozzi, Wong, Abe, & Bergami, 2000). This means that people could be commuting together and sharing the same transport, making BSS a less attractive mean of transportation; however, there is not enough data to validate this hypothesis.

However, the bar variable is one of the variables that only affected women. The female departure model concluded that stations with a higher number of bars in the vicinity negatively impact BSS adherence. Like restaurants, the literature pointed out this variable as an advantageous factor for the stations' increase in arrival and departure rates. However, it is quite intuitive why this variable negatively impacts women's departure model. Bars act as an important proxy for alcohol-related activities. Many studies associate proximity to bars with an increase in crime because these establishments tend to attract a large number of people who are typically consuming non-inhibitors (Groff & Lockwood, 2014; Roncek & Bell, 2005). Women tendentiously avoid neighborhood areas where they can be more vulnerable to sexual assault (Law, 1999).

5.1.4. Education Facilities

This section explains the results for parameters related to education facilities variables. The proximity of universities to the BSS station had no impact whatsoever on any model. This is because as the distance from the university to the station expands, the university's impact on the arrival and departure rate decreases for both genders (K. Wang & Akar, 2019; K. Wang et al., 2018). The city of Seattle has a large part of its universities in the same area, so the number of stations that account in their 500-meter radius with a university is low, resulting in this variable being not significant for the models.

The school variable (private and public schools) positively affects both genders' bike share trip attractions. The results are not surprising because studies have shown that gender was not a statistically significant variable in explaining the difference in kids' choice - which ranges from kindergarten to senior year of high school - to commute by bicycle or foot in Seattle (Kerr et al., 2006).

Libraries in the area around bike share stations may significantly reduce the bike share departure among female riders. Women's clothing has a disadvantage over men's clothing. For fashion reasons, women's clothing was seen a fall in the number and size of pockets since the nineteenth century. This change in women's clothing resulted in females turning to handbags as a way to carry personal things, identification, cell phone, and other objects (Burman, 2002). Because of this, women, unlike men, aside from the backpack with schoolbooks and study material, must also carry a handbag. This can become a safety hazer if the bicycle does not have the conditions to carry multiple items – which is the case with pronto cycle share bicycles (Appendix C – Section 9.3) (Schepers & Klein Wolt, 2012). For women, safety is a major concern, so this can influence the bike share usage of females.

5.1.5. Green Spaces

In this paper, green spaces are consistently mainly of local parks. The number of green spaces around bike share stations significantly impacts bike share usage among female riders (departure model). These results are reasonable and in view with the literature. As established, women more often than their male counterparts use BSS for leisure and physical activities (S. L. Handy, 2011). For that reason, green spaces like parks and others are seen by female riders as attractive places to cycle (K. Wang & Akar, 2019).

5.1.6. Supermarkets

As expected, the departure rates increase when within a 500-meter radius of a Pronto Cycle Share station, there is a superior number of supermarkets and other grocery stores. This is supported by the fact that the variable supermarkets is statistically significant and has a positive coefficient on both genders' departure models. This can be explained by the fact that these stores are usually located in the city's CBD (Central Business District), usually these types of urban environments are associated with the drawing of bicycling users (Faghih-Imani et al., 2014; K. Wang & Akar, 2019).

5.1.7. Street Lights

In line with the results obtained by (Chen et al., 2018), the presence of street lights is outlined as a variable with statically positive significance on the share of trip departures made by men and women and the share of trip arrival made by men. The number of street lights is essential for cycling environments since appropriate lighting is linked to safety and reassurance (Peters, 2013). As previously established, safety is recognized as a factor that influences cycling (Winters et al., 2010).

Through the results described in the assumption testing section of chapter 4, it is possible to conclude that from the four models presented, three gather the condition necessary to be considered valid. These results and their implications are as relevant as the model analysis per se since this result will indicate if the results gathered can be considered trustworthy. The only model that failed the assumption test was the female arrival model, which was also the only model that was not statistically significant. Because the assumptions are violated, then the results obtained from the multiple linear regression of the female arrival model are unreliable, making it impossible to extract any conclusion regarding this model.

Finally, it is important to refer that the built environment can be used to explain the overall bike-share ridership for both genders. Moreover, the number of variables affecting the attraction to a particular station is superior for women than their male counterparts. According to the established literature, this states that women's mobility is more easily impacted by external factors than men's mobility (Sánchez & González, 2016).

6. CONCLUSIONS

Over the last years, sustainability and concerns about environmental problems as increased considerably. Therefore, understanding the variables that can significantly impact the utilization of sustainable transportation modes might help unravel the complexity that cities face when creating policies that intend to increase the number of citizens, both men, and women, using BSS as the main mean of transportation. This research aimed to comprehensively study the effect the built environment has on the adhesion of bike-share systems for different genders. It was attempted to ascertain the most relevant variables among a wide variety presented in the literature when studying the gender gap built environment created on bicycle ridership.

The first theoretical contribution is that joining these variables in the case study of Seattle allowed to draw conclusions and further enrich the literature on the topic. The combination of such variables establishes the importance of the built environment and BSS adhesion for each gender.

An additional theoretical contribution made by this research concluded that when considering bicycles as the mode of transportation, the known fact that women make shorter trips than their male counterparts is questioned. The results show that women present longer trips in both distance and duration when compared with men.

The practical contributions are that this research brings new information to help city planners develop strategies according to users' needs.

The results show that the variables with the highest positive impact are bike lanes for women. The priority should be to improve and build better and more sophisticated bike lanes as the primary strategy to increase the number of female riders. The main barrier to females' choice of stations is restaurants. It is essential to understand why this variable had such a negative impact and emerge with strategies that will remove this impediment to women's bike ridership. Parks – green spaces – and street lights are also variables that have a significant impact, and because of this, cities should try to increase the area of green space and better light the city to promote the share of female readership.

Considering the arguments previously mentioned and having in mind that the intent is to create a better environment for female bicycle riders and not obstruct the already existing male rider, the built environment variable that impacts men should also be discussed. The results show that, for men, the variables with the highest positive impact are schools. As so, ways to guarantee the safety of users of younger ages should also be a priority. The main barrier of male users is just like their counterpart restaurants.

In conclusion, strong evidence was presented in this work that there is a correlation between the built environment and each gender's adhesion to the bike-share system. Successfully results on this model were obtained. The conclusion arrived shows that the number of variables affecting the attraction to a particular station is superior for women than for men. Ultimately women’s mobility is more easily impacted by factors of the built environment than men’s mobility. Nonetheless, the model that aims to explain the impact the built environment has on arrival rates for female riders returns results impossible to sustain, which sets the basis for further research among these variables to confirm or refute such hypotheses.

7. LIMITATIONS AND RECOMMENDATIONS FOR FUTURE WORKS

Despite the valuable insights brought by this investigation, some limitations should be recognized when investigating this subject in future studies. First, the sample obtained in this study - Seattle's Pronto Cycle Share - was not as desirable because the trip information only goes until 2017, making the sample data outdated. Another limitation that should be considered is that it was not possible to uncover the gender of the user without a membership leaving a subnational number of trips out of the study. Moreover, as mentioned in the literature review section, this investigation only considers the conservative perspective of addressing gender by acknowledging only males and females. For this reason, a part of the sample that does not identify as either was not considered and therefore not studied.

Still, regarding the sample data, given the asymmetry in the number of trips made by each gender, it was challenging to get a representative conclusion when comparing the results. Increasing the sample in quantity terms and quality is one of the points that should be considered as a way to ensure the data justly and rightly represent the population under study.

Second, part of the data collection was based on online sharing crowdsourced geotagged websites that do not have the validity of their sources checked. If the information were provided by an institution or organization whose primary job was to confirm and validate the geolocation and number of the infrastructure would have enabled a better understanding of the results.

Third, the metrics regarding the distance of the trips were obtained by computing the linear distance between each station. If, instead of the estimated distance between stations, the route of the trips was available, it would be possible in future works to evaluate which features of the path are chosen by men or women. This way, there would be enough evidence to confirm whether the longer distances are due to leisure and physical activity or to avoid shorter paths that are more dangerous.

Additionally, since one of the models was disregarded, it would also be interesting to study how a combination of other variables would influence the number of female riders using a particular arrival station.

Finally, the data sample was obtained from Seattle. Thus, the results cannot be implied in other countries. However, future research could consider a more comprehensive sample to cover people from different countries and compare the different ways BSS behaves in other cities. Investing in this type of research would improve the quality of the results, and it would be a way to address the results according to the city users.

To conclude, in further research, it would be interesting to analyze other variables more related to recreation and leisure activities. In this investigation, the aim was to analyze the gender gap in bike-share usage using data from Seattle City. The correlation between the different genders and the built environment of bike-share may be different in other urban settings. However, the analytic methods discussed in this research are applicable everywhere.

8. BIBLIOGRAPHY

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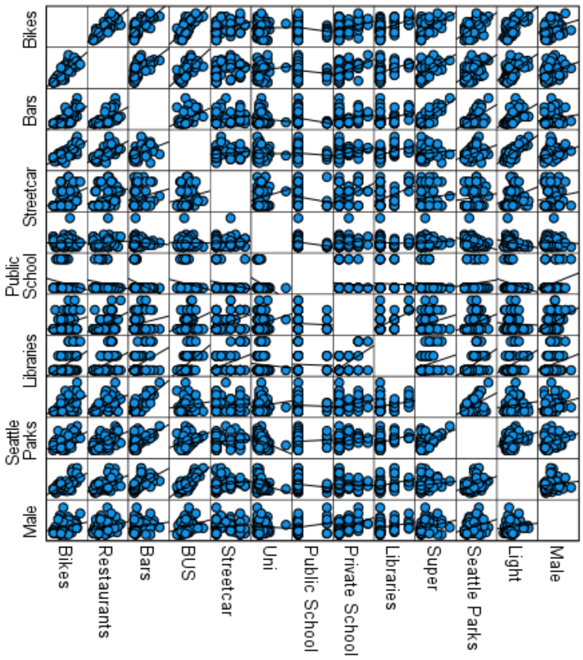
9. APPENDIX

9.1. APPENDIX A – PLOTS

9.1.1. Linear Regression



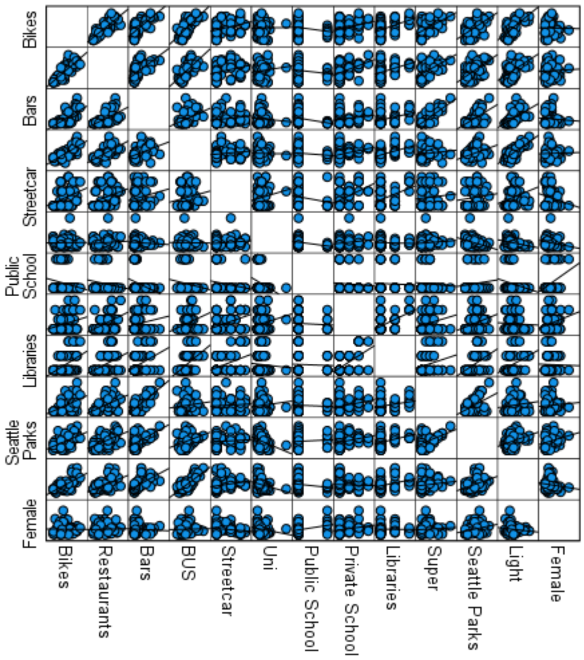
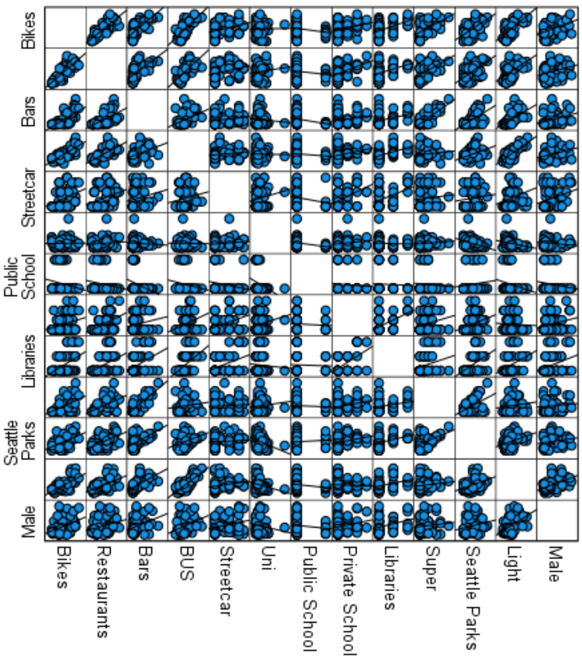


Figure A1 – Scatterplot Male Departure

Figure A2 – Scatterplot Female Departure



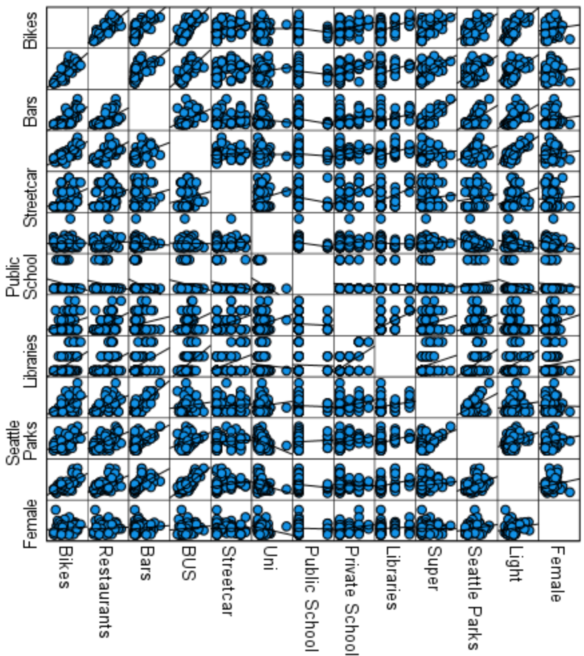


Figure A3 – Scatterplot Male Arrival Figure A4 – Scatterplot Female Arrival

9.1.2. Scatterplot

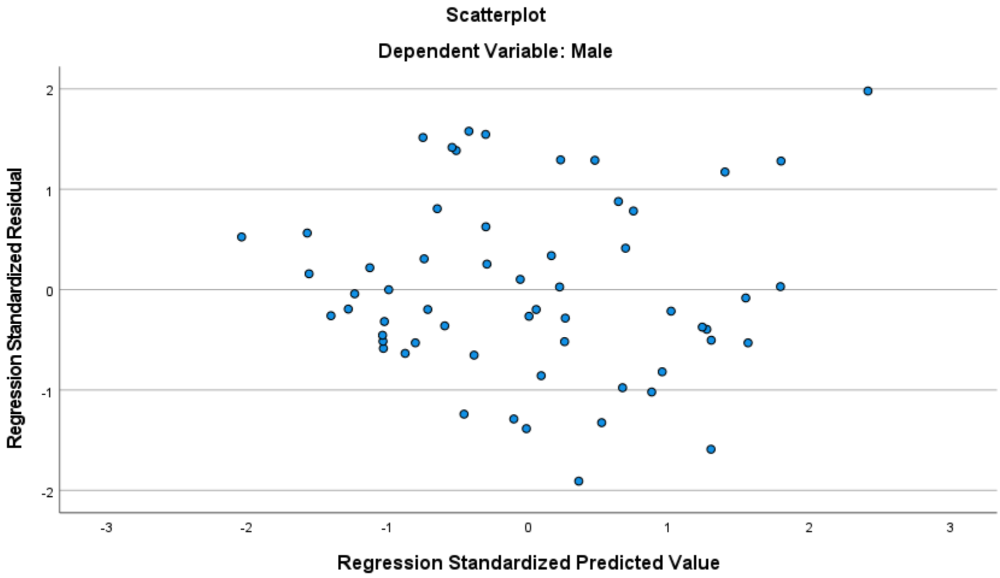


Figure A5– Scatterplot Residuals Male Departure

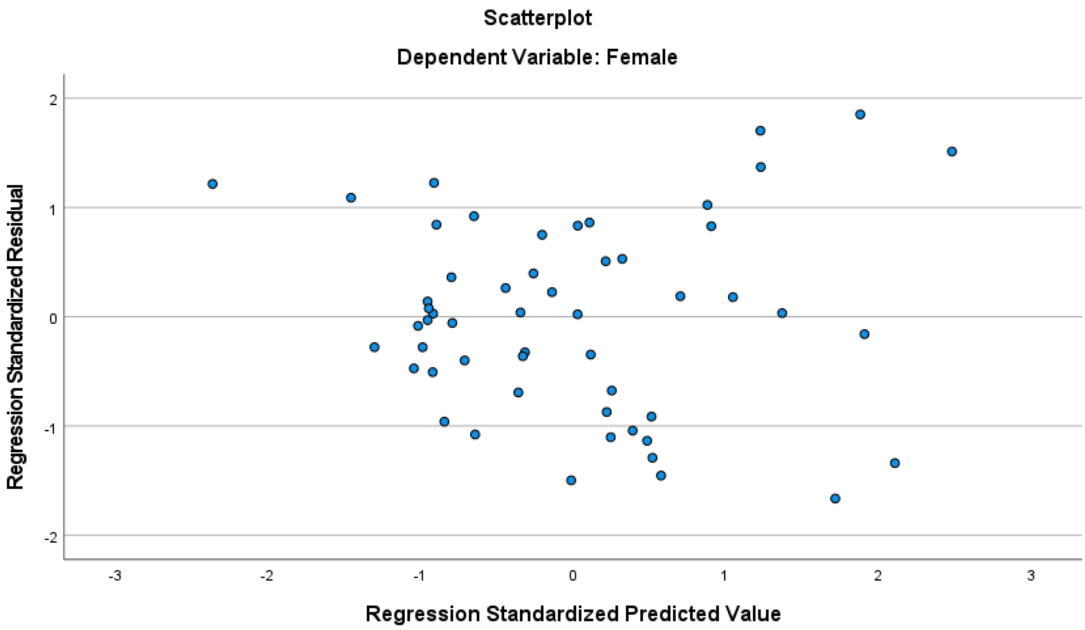


Figure A6– Scatterplot Residuals Female Departure

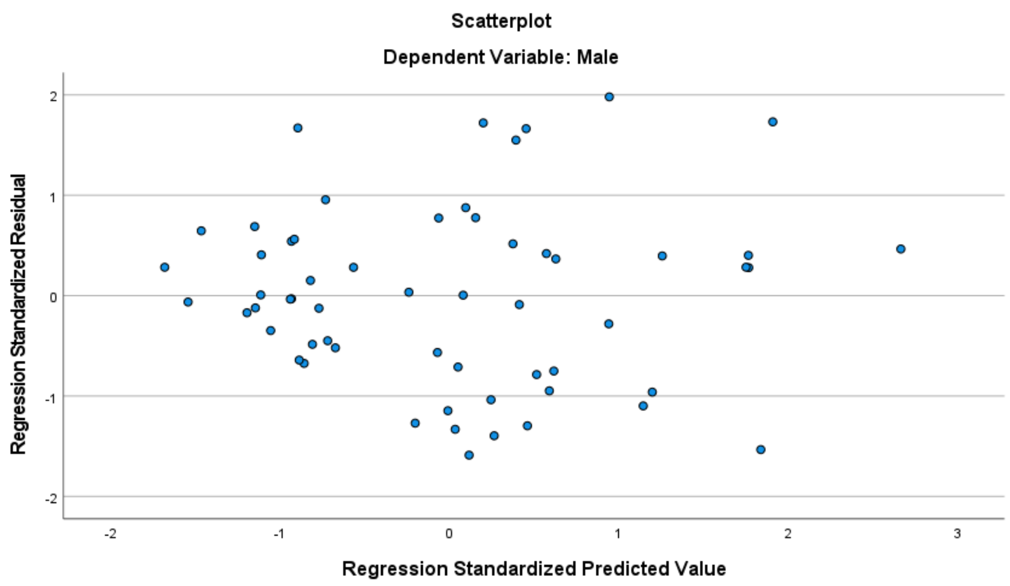


Figure A7– Scatterplot Residuals Male Arrival

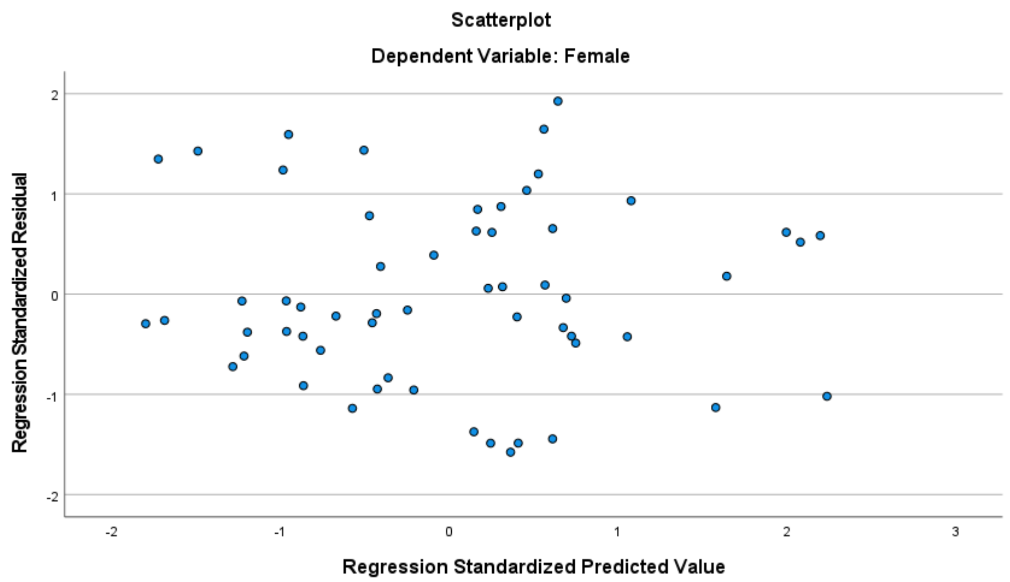


Figure A8– Scatterplot Residuals Female Arrival

9.2. Appendix B – Normality Test

Male Departure	Kolmogorov-Smirnov			Shapiro-Wilks		
	Statistic	df	Sig.	Statistic	df	Sig.

Unstandardized Residuals	0.103	58	0.194	0.974	58	0.257
Standardized Residuals	0.103	58	0.194	0.974	58	0.257

Table B1 – Normality Test Male Departure

Female Departure	**Kolmogorov-Smirnov**			**Shapiro-Wilks**		
	Statistic	**df**	**Sig.**	**Statistic**	**df**	**Sig.**
Unstandardized Residuals	0.068	54	0.200	0.982	54	0.580
Standardized Residuals	0.068	54	0.200	0.982	54	0.580

Table B2 – Normality Test Female Departure

Male Arrival	**Kolmogorov-Smirnov**			**Shapiro-Wilks**		
	Statistic	**df**	**Sig.**	**Statistic**	**df**	**Sig.**
Unstandardized Residuals	0.063	58	0.200	0.971	58	0.186
Standardized Residuals	0.063	58	0.200	0.971	58	0.186

Table B3 – Normality Test Male Arrival

Female Arrival	**Kolmogorov-Smirnov**			**Shapiro-Wilks**		
	Statistic	**df**	**Sig.**	**Statistic**	**df**	**Sig.**
Unstandardized Residuals	0.087	58	0.200	0.975	58	0.266
Standardized Residuals	0.087	58	0.200	0.975	58	0.266

Table B4 – Normality Test Female Arrival

9.3. Appendix C – Pronto Cycle Share