Assessing Pedestrians' Perception of the Urban Environment in Different Times of the Day

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Statement

I declare that this document is my original work and that it fulfils all the requirements of the University of Lisbon's Code of Conduct and Good Practices.

Declaração

Declaro que o presente documento é um trabalho original da minha autoria e que cumpre todos os requisitos do Código de Conduta e Boas Práticas da Universidade de Lisboa.

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Abstract

This work seeks to identify the attributes of the urban space that are considered barriers to walking from the pedestrians' perspective. Besides, it intends to analyse if pedestrians perceive them differently throughout the day. A survey was created to capture pedestrians' perceptions of certain urban attributes. As a case study, respondents in Lisbon were asked to evaluate the statements dichotomously. A Rasch model is used to analyse the data obtained ($n = 1031$), ranking the difficulty of the barriers identified and the pedestrians' probability to overcome them. When considering the aggregated data, results show that the most difficult barriers were the presence of litter and parked vehicles (both on public parking and illegally on the lane), traffic volume, air/noise pollution, and sidewalk condition. After aggregating the data into three time periods (peak, off-peak, and lunch time), some variation on perceptions was observed. Three out of the five most difficult barriers are the same for all time periods. Sidewalk condition and the presence of many people are identified at peak hours, while issues related to air/noise pollution and illegally parked cars on lane are detected at off-peak and lunch time. These differences on the perceived walkability indicate that public policies can be elaborated to address the barriers on certain hours of the day.

Keywords

Walkability, Urban Space, Perceptions, Dynamic Allocation.

Resumo

Este trabalho busca identificar elementos do espaço urbano que são considerados barreiras para a caminhabilidade a partir da perspectiva dos peões. Além disso, ele também pretende analisar se os pedestres os percebem de forma diferente ao longo do dia. Foi criada uma pesquisa para captar as perceções dos peões sobre determinados atributos urbanos. Como estudo de caso, os entrevistados em Lisboa foram solicitados a avaliar as declarações de forma dicotômica. Um modelo Rasch é usado para analisar os dados obtidos ($n = 1031$), classificando a dificuldade das barreiras identificadas e a probabilidade dos peões de superá-las. Ao considerar os dados agregados, os resultados mostram que as barreiras mais difíceis foram a presença de lixo e de veículos estacionados (tanto em estacionamentos públicos, quanto ilegalmente na via), o volume de tráfego, a poluição sonora/do ar e as condições do passeio. Após agregar os dados em três períodos de tempo (ponta, fora de ponta e horário de almoço), observou-se alguma variação nas perceções. Três das cinco barreiras mais difíceis são as mesmas em todos os períodos de tempo. As condições do passeio e a presença de muitas pessoas são identificadas nos horários de ponta, enquanto os problemas relacionados à poluição do ar/sonora e aos carros estacionados ilegalmente na pista são detectados fora do horário de ponta e no horário de almoço. Essas diferenças na caminhabilidade percebida indicam que políticas públicas podem ser elaboradas para lidar com barreiras em determinados horários do dia.

Palavras-chave

Caminhabilidade, espaço urbano, percepções, alcoação dinâmica.

Table of Contents

Table of Figures

List of Tables

Nomenclature

EFA – Exploratory Factor Analysis

ICC – Item Characteristic Curve

IRT – Item Response Theory

LOS – Level of Service

MIMIC – Multiple Indicator and Multiple Cause

OLS – Ordinary Least Squares

PLOS – Pedestrian Level of Service

QoS – Quality of Service

RM – Rasch Model

SEM – Structural Equation Modelling

SOR – Stimulus-Organism-Response

SPI – Service and Performance Indicator

1. INTRODUCTION

Urban space is scarce and contested, as different urban functions and transportation modes compete for space (Jones et al., 2008; Valença et al., 2021). On one hand, the width of the street assigned to traffic lanes represents the need of fast and efficient travels (*i.e.*, low generalised cost from origin to destination). It has its own dilemma regarding multimodal demand and the competition between transport modes. On the other hand, part of the cross section of the street is dedicated to accessing activities. On this case, its main role does not regard rapid travels, but instead it allows people to access places and have social interactions, through the assignment of space to parking spaces and sidewalks (Valença et al., 2021). Furthermore, these disputes intensify in certain hours of the day. The distribution of activities over the territory generates a fluctuation on travel patterns on both space and time for different transport modes. For example, as traffic lanes are designed for peak flows, space is usually underutilised during off-peak hours (Berghauser Pont et al., 2019; Ortúzar & Willumsen, 2011; Valença et al., 2024b). Thus, the conflicts identified during different hours of the day may differ, which could indicate that people perceive the environment differently.

In this context, the question this research seeks to answer is: "How do pedestrians perceive walkability attributes of the urban environment at different times of day?". Its main goal is to analyse how pedestrians perceive the environment and how these different urban elements can hinder walking. In addition, the study attempts to identify how fluctuations on travel demand along the day can influence pedestrians' perceptions about the environment. By computing the difficulty of potential barriers, namely the urban attributes considered, and people's ability to overcome them, this study tries to evaluate the obstacles presented to pedestrian while they use the urban space, namely walking, and using outdoor seating areas, including public benches and restaurant seats.

As a case study, a survey was applied in a street identified by Valença et al. (2024b) as a complex zone, meaning it has a limited and disputed space, which is further explored on Section 3.2. A questionnaire composed of twenty-nine statements was created based on the multidimensional 5Cs layout (Gardner et al., 1996; Transport for London, 2004), which was later expanded to 7Cs by Moura et al. (2017). This framework represents seven dimensions that explain how walkable the urban space is: *Connectivity*, *Convenience*, *Comfort*, *Conviviality*, *Conspicuous*, *Coexistence*, and *Commitment*. The survey's goal is to capture pedestrians' perceptions on the elements of the urban environment. It was applied from 8 a.m. to 8 p.m. (with two one hour breaks in between) during four working days to allow the segregation of data into different time periods: peak, off-peak, and lunch time.

Data analysis is based on the Rasch Model (RM), an item response theory (IRT) model. It evaluates the difficulty of items, namely the elements of the urban environment, and it estimates a latent trait that characterises people's ability to overcome the barriers presented to them (Hambleton et al., 1991). Pedestrians with higher abilities have higher probabilities on overcoming the obstacles. The application of the survey hours days allows the analysis of how the perceptions can change during the day, indicating that corrective measures can be proposed either statically (i.e., permanent) or dynamically (i.e., applied only on certain periods of the day), depending on the characteristics of the perceived barriers.

It is crucial to mention that the implementation of design changes is highly dependent on policy goals and very context-oriented (Moura et al., 2017; Valença et al., 2024a). It means that adopting measures that redesigns urban space requires previous studies, such as this one, to understand the local context (e.g., travel patterns, modal share, engagement of local authorities). Ultimately, the inclusion of public perspectives on the policy-making process may lead to policies perceived as fair, efficient, and beneficial, which are a first step for public acceptance (Banister, 2008).

The impact of the present study is twofold: (1) it is a bottom-up approach to urban redesign, as it endorses the inclusion of the public perspective into the policy-making process; and (2) it supports an increase on efficiency on urban space allocation (e.g., while it is being underutilised), as it highlights the differences of travel patterns throughout the day, allowing different uses of the urban space at different times.

1.1. Document's Structure

This work is divided as follows: in Section 2 a literature review is made to support the scenario described in Section 1, providing a more in-depth description of some walkability assessments and the elements that may influence walkability. Section 3 presents a methodology of the study, followed by the presentation of the results obtained and its discussion on Section 4. Section 5 shows the concluding remarks, including limitations and possible paths for future research.

2. STATE OF THE ART

On this section, a review of the current literature is presented to explore two main topics. First, a presentation of walkability assessments is made, highlighting how context-oriented and dependent on different characteristics they are (Lo, 2009; Moura et al., 2017; Valença et al., 2024a). Furthermore, this section also presents the urban elements (or attributes) that may influence walkability.

2.1. Walkability Evaluation

Walkability is considered a measure of how walkable a place is, but it can refer to different aspects of the environment. Forsyth (2015) identified that walkable places are mostly related to characteristics that ensure safety and security. Besides, a pedestrian-oriented design, where destinations are close to trip origin (*e.g.*, land use mix) and housing density seems to induce walking as a transport mode (Cervero & Kockelman, 1997). Combined with a well-maintained infrastructure, urban spaces should be pleasurable, enticing and barrier-free environments, hence creating “a general sense of liveliness, vitality, sociability, or vibrancy” (Forsyth, 2015, p. 10). However, there is no consensus on how to evaluate and validate walkability indicators, as different attributes, scales, and assessment methods are used across studies, often providing diverging results (Arellana et al., 2020; Fonseca et al., 2022; Moura et al., 2017).

The first attempt to evaluate walking environments follows the definition of vehicular level of service (LOS), considering flow and capacity measures, such as pedestrian density, flow rate and speed (Lo, 2009; Rodriguez-Valencia et al., 2022). However, only considering such variables may be misleading, since additional environmental factors (*e.g.*, comfort, convenience, safety, security) are found to also contribute to pedestrian level of service (PLOS) (TRB, 2000). For example, an empty, poor-lit sidewalk in an industrial neighbourhood would be ranked higher than a busy commercial one, as the latter presents higher pedestrian density (Lo, 2009). Over time, walkability indices encompass factors associated with PLOS (*e.g.*, pedestrian and vehicular flow characteristics, elements of the built environment, and user’s perceptions), but it also considers broader aspects related to accessibility, such as topology, proximity to destination, attraction of facilities, and pedestrian infrastructure (Nag et al., 2020).

Still in the 90’s, Transport for London established five desirable factors that may improve and encourage walking: *Connectivity*, *Conviviality*, *Convenience*, *Comfort*, and *Conspicuous* (Gardner et al., 1996; Transport for London, 2004). Later, besides adding two other factors (*Coexistence* and *Commitment*), Moura et al. (2017) developed a framework for assessing walkability based on them. The seven dimensions (7Cs) describe aspects of walkable environments, as shown on Table 1. Some of these factors can often overlap, as different dimensions can have an impact on each other (Vallejo-Borda et al., 2020).

Table 1: Description of the 7Cs

Dimensions	Description
Connectivity	the extent to which the network links origins and destinations. It is related to the creation of more walking trips opportunities and making them shorter and seamless.
Conviviality	the extent to which walking is a pleasurable activity, related to the influence the environment has on the interaction between pedestrians.
Conspicuous	the extent to which the environment is inviting and supportive to walking regarding the provision of lighting and signalling, and the indication of public services. It pays regard to legibility, complexity, coherence, and natural surveillance, which can also translate to safety concerns.
Comfort	the extent to which walking is made comfortable for people with different capabilities. It associates urban amenities with the pedestrians' perception of comfort during the walking experience.
Convenience	the extent to which walking is an efficient and unobstructed activity. It seeks to address the relation between walking and land use.
Coexistence	the extent to which pedestrians and other modes can coexist with minimum disturbance for the former. Traffic safety can critically influence walking levels, as the perception of unsafe environments can hinder people from walking.
Commitment	the extent to which local communities and administration are engaged in promoting pedestrian-friendly urban environments. It also accounts for the liability and the responsibility from institutions.

Source: Obtained from Gardner et al. (1996), Moura et al. (2017), and Transport for London (2004)

In most cases, service or performance indicators (SPIs) are based on objective and measurable characteristics, generating a proxy for perceived satisfaction or Quality of Service (QoS) (Raad & Burke, 2018). However, the quality of the environment is not only directly affected by the physical features, but also indirectly influenced through perceptions (Ewing & Handy, 2009). As explained by Rodriguez-Valencia et al. (2022), operational and geometric variables may ensure infrastructure function and performance, but perceptual inputs are important to understand user's perceived QoS (*e.g.*, safety, security, comfort). Thus, perceptions can be used for both validating and estimating walkability scores (Moura et al., 2017; Rodriguez-Valencia et al., 2020). Moreover, based on a stimulus-organism-response (SOR) model, Ma & Cao (2019) support the idea that perceptions can partially mediate the influence the urban environment has on travel behaviour.

It is important to highlight that objective and subjective measures of the same attribute may differ. Gebel et al. (2009) explore the mismatch between objective and subjective walkability levels. They conclude that roughly one third of residents erroneously describe their neighbourhoods regarding how walkable they were, meaning objective and subjective measures may be misaligned. For example, in an assessment model, capturing perceived safety (*i.e.*, well-lit streets, without entrapment spots) may be more important than considering the actual safety (*i.e.*, reported crimes), as the perception of an unsafe environment may hinder people from walking (Forsyth, 2015).

By including both objective and subjective variables into evaluation models, Rodriguez-Valencia et al. (2020) are able to explore the influence of user perception on sidewalk QoS in Bogotá (Colombia). Ordinary least squares models (OLS) are developed using different combinations of variables, including geometric, operational, and perceptual factors. They concluded that perceptions play an expressive role in explaining the variance in the models. In fact, when considering the contribution of each group of variables, perceptual variables account for at least 62%, with minor contribution of geometric and operational variables. Similarly, Vallejo-Borda et al. (2020) used an ordered probit multiple indicator and multiple cause (MIMIC) to forecast the QoS of sidewalks from pedestrians' perceptions and objective characteristics, quantifying their effects. Forecasted QoS values matched observed QoS in 26 out of 30 sidewalks, indicating a good fit, thereby highlighting the impact of the physical environment on pedestrians' perception, and, subsequently, on SPIs.

Section 2.2 explains in further detail which elements of the urban environment are usually incorporated in walkability assessments.

2.2. Urban Attributes and Walkability

Many studies have explored the influence of the built environment on travel demand. Cervero & Kockelman (1997) introduced the 3Ds (density, diversity, and design) and highlighted its negative impact on the generation of motorised trips, shedding light on how the environment could potentially induce walking trips. These factors were later expanded to include destination accessibility, distance to transit, demand management, and demographics (Ewing & Cervero, 2010). Although the last two are not variables related to the environment, they may influence travel demand (*e.g.*, vehicle miles travelled) and mode choice. As stated in Section 2.1, pedestrian-oriented designs seem to have a marginal contribution on the generation of walking trips, but they may influence accessibility, and hence impact the perceived satisfaction and QoS (Ewing & Cervero, 2001; Raad & Burke, 2018).

To identify the most important factors for assessing PLOS, Raad & Burke (2018) perform a systematic review of literature on the topic. They concluded that the factors usually fall into one of three dimensions: comfort, safety and mobility. In another systematic review of literature on the effects of the built environment on walkability, Fonseca et al. (2022) divide the attributes into 6 categories, do not seem substantially different from the ones stated by Raad & Burke (2018). Besides comfort and safety, the study includes categories regarding street connectivity, accessibility and land use. It sheds light on the importance of the access function of the street and not only on the need of rapid travels. In addition, they also highlight design elements that describe the street in a micro-scale. These are defined as perceptual qualities, which try to explain how pedestrian perceive and process certain characteristics of the urban environment (Ewing et al., 2006).

Table 2 shows commonly used urban elements on the papers analysed. Studies often group the items differently, but there seems to be a general consensus on a big part of the elements. Regarding the difficulties for pedestrians crossing, some researchers emphasise the need of crossings aids (*e.g.*, signalling, markings, speed bumps, traffic speed devices) to provide safety on crosswalks (Arellana et al., 2020; Raad & Burke, 2018; Rodriguez-Valencia et al., 2020; Talavera-Garcia & Soria-Lara, 2015). It becomes evident that ease of crossings is highly correlated to traffic speed. Similarly, some studies explore how the lack of crossing opportunities can cause insecurity and hinder walking (Herrmann-Lunecke et al., 2021).

Table 2: Urban attributes that may influence walkability retrieved from the literature

Item	Arellana et al. (2020)	Bivina & Parida (2019)	Fonseca et al. (2022)	Herrmann-Lunecke et al. (2021)	Jahan et al. (2020)	Lo (2009)	Moura et al. (2017)	Nag et al. (2020)	Pikora et al. (2003)	Raad & Burke (2018)	Rodriguez-Valencia et al. (2020)	Rodriguez-Valencia et al. (2022)	Talavera-Garcia & Soria-Lara (2015)	Vallejo-Borda et al. (2020)
Accessible destinations					X	X	X	X				X		X
Buffer					X	X		X		X	X		X	X
Commerce and services	X					X	X		X				X	
Crossing opportunities				X		X				X				
Ease at crossings	X			X		X	X			X	X		X	
Lighting		X		X	X			X	X	X	X	X	X	
Litter	X	X		X	X	X			X			X	X	
On-street parking					X				X	X			X	
Orientation							X	X						
Parking on sidewalk	X			X	X					X			X	
Pollution				X					X		X	X		
Overcrowding	X		X	X	X					X	X	X	X	X
Security	X	X			X	X		X		X	X	X		
Shading						X		X	X	X			X	
Sidewalk condition	X		X	X	X		X	X	X	X	X	X	X	X
Sidewalk continuity	X	X	X			X		X	X				X	
Sidewalk obstacles	X	X	X		X	X		X					X	
Sidewalk width	X	X	X	X	X		X	X	X	X	X		X	X
Street slope	X		X				X						X	
Street furniture		X	X			X		X		X		X	X	X
Traffic speed		X	X		X	X		X	X	X	X		X	X
Traffic volume	X	X		X				X	X	X			X	X
Visual pollution	X			X										

Source: Author

Many studies include trees as favourable elements to walking. It can generate cooling and shading effects, increasing pedestrian comfort, giving also a more aesthetic look to the environment (Arellana et al., 2020; Fonseca et al., 2022; Herrmann-Lunecke et al., 2021; Rodriguez-Valencia et al., 2020, 2022; Talavera-Garcia & Soria-Lara, 2015). However, few studies characterise which elements define the aesthetical appeal. It could mean clean architectural designs, but also a well-maintained landscape (*e.g.*, with no visible litter) and the presence of natural elements (Arellana et al., 2020; Johansson et al., 2016; Pikora et al., 2003).

Regarding parking, some studies explore the impacts that parked cars may have on pedestrian activity. Many walkability assessments consider that vehicles parked on the sidewalk might influence perceived walkability, as they can interrupt pedestrian flow (Arellana et al., 2020; Jahan et al., 2020). Similarly, some studies explore how on-street parking may decrease pedestrian accessibility to sidewalks, while also serving as a buffer, creating a separation between pedestrians and traffic flow and increasing the perception of comfort (Jahan et al., 2020; Pikora et al., 2003; Raad & Burke, 2018). Moreover, double-parking (*e.g.*., illegally parked vehicles on traffic lanes) causes bottlenecks on the traffic flow, influencing the generation of congestion and possibly impacting accessibility and perceived walkability (Jardim et al., 2022; Zoika et al., 2021).

Elements regarding the use of space are also considered in some studies. This topic is regularly associated with land-use mix, which is said to encourage walking trips (Cervero & Kockelman, 1997). The presence of commercial activities and services attract trips, hence generating demand for accessibility (Talavera-Garcia & Soria-Lara, 2015). Micro-elements regarding accessibility, such as steps, ramps, and other elements that may facilitate or hinder walking, are often considered in studies (Jahan et al., 2020; Rodriguez-Valencia et al., 2022; Vallejo-Borda et al., 2020). Concerns related to the accessibility to transit systems are also deemed important by some researchers, both in terms of proximity and physical accessibility (Fonseca et al., 2022; Vallejo-Borda et al., 2020). Similarly, some studies explore the importance of promoting social interactions in the urban space, such as in terraces and meeting places (Ewing & Handy, 2009; Moura et al., 2017; Talavera-Garcia & Soria-Lara, 2015). This means that empty streets could hinder people from using the public space.

However, the importance of urban attributes can vary according to the scale of analysis, purpose of the trip, pedestrian type (*e.g.*, age, gender, physical activity levels), urban context, and cultural aspects (Lo, 2009; Ma & Cao, 2019; Moura et al., 2017). Walkability assessments are very context dependent. Differences in morphologies, cultural and historical backgrounds, and urban issues, can reflect different walkable conditions, thus generating different results of walkability assessments (Fonseca et al., 2022). Arellana et al. (2020) highlight the differences on the importance of urban attributes in different contexts (*e.g.*, city location, city size), questioning if results are transferable among regions. This present study addresses how some variables can vary also according to the time of the day, a topic that has not been widely analysed in the literature to date, to the best of our knowledge.

For that matter, Bivina & Parida (2019) and Jahan et al. (2020) explore the impact some attributes may have on PLOS in India and Bangladesh, respectively. They use structural equation modelling (SEM) to assess user's perception and to identify the most influential variables on pedestrian satisfaction. For their context, security (*e.g.*, robbery, harassment, police patrolling), comfort (*e.g.*, cleanliness), safety (*e.g.*, traffic speed and volume) and convenience (*e.g.*, obstructed and poorly maintained sidewalk) were found to be the most influential elements. At the same time, studies carried out in the Global South showed similar results. Arellana et al. (2020) explore critical factors for measuring walkability in Barranquilla (Colombia) from a rank perception survey, concluding that safety (associated with traffic) and security (associated with crime), sidewalk condition and cleanliness are the most relevant ones. Herrmann-Lunecke et al. (2021) conducted walking interviews in Santiago (Chile), where participants were asked to state their feelings in relation to urban elements. Wellbeing seems to be most related to sidewalk width and condition, and the presence of local shops and trees. Stress is associated with the presence of litter, traffic volume and noise, high-rise buildings, besides the lack of green areas and the existence of graffiti. On the other hand, Moura et al. (2017) found that in Lisbon (Portugal) sidewalk continuity and condition, service hours, and traffic safety were the most relevant factors, showing that crime safety seem not to be as important as in other contexts. In this sense, results from different assessments may not represent the same concerns.

3. METHODOLOGY

3.1. Methodological Framework

The data to assess pedestrians' perceptions of the environment was obtained from a street survey. A questionnaire was created aiming to capture which urban elements are considered barriers to pedestrians. It was applied to a case study in Rua Morais Soares, Lisbon (Portugal) during different times of the day to allow the further identification of fluctuations of the perceived barriers. After data collection, an item-response theory (IRT) method was applied to transform the dataset into a numerical scale. A Rasch model (RM) was applied, which ranks the perceived barriers according to their difficulties to be overcome, as well as the probability of people on overcoming them. This is particularly relevant because elaborating public policies from obstacles identified by pedestrians may increase public acceptance, crucial step in promoting sustainable mobility (Banister, 2008; Rodriguez-Valencia et al., 2022).

3.2. Case Study

The selection of the study area was made by Valença et al. (2024b), where they define the criteria for selecting complex sites (*i.e.*, zones with a high potential for dynamically allocating road space). Their work's methodology is based on the degree of competition for space between the different street functions: mobility and access. While the former represents the need to minimise travel time, the latter characterises the street as a destination in itself, as a place where people spend time and take part on diverse activities (Jones & Boujenko, 2009). Valença et al. (2021) support the idea of equitably allocating road space between these two functions.

The indicators used by Valença et al. (2024b) are based on three components: land use, road network and a temporal dimension. The first is defined by the populational density and land use diversity of the area. The second is related to connectivity, mobility and access indicators, which are characterised by the number of shortest paths on a given node. The temporal component corresponds to the analysis of traffic congestion in different hours of the day and the frequency of the public transport network. One of the streets that resulted from their application on the Lisbon municipality was Rua Morais Soares (Figure 1).

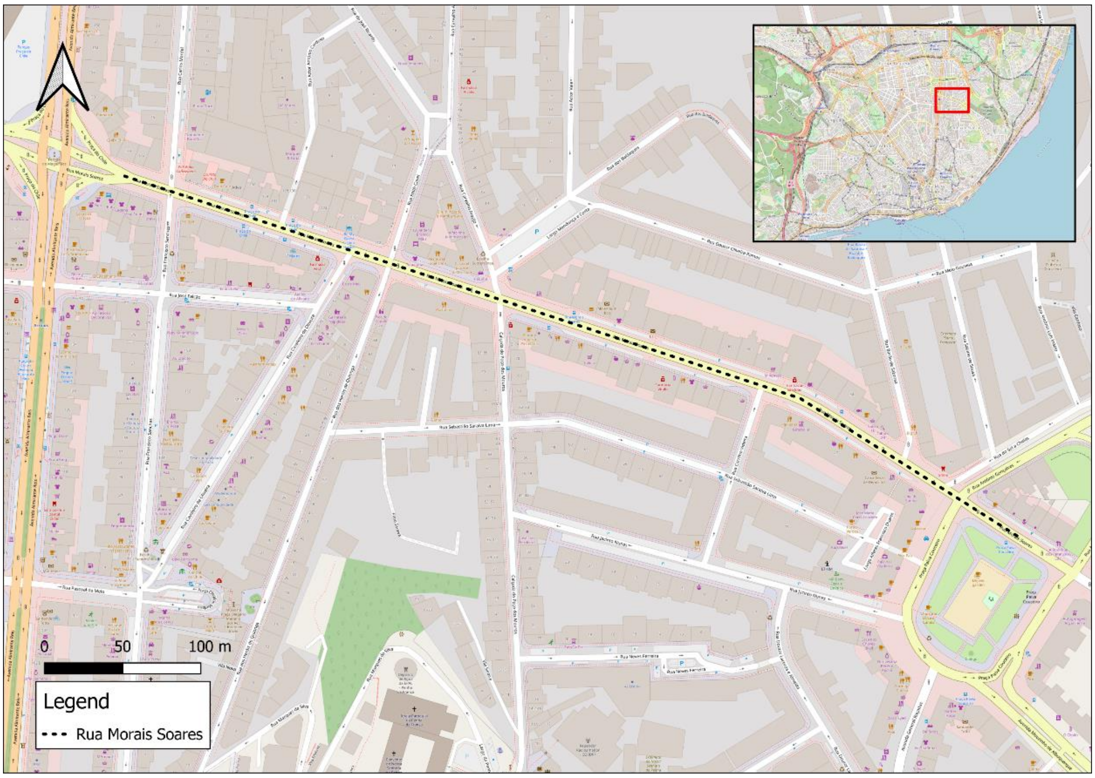

Figure 1: Location of Rua Morais Soares. Source: Author

3.3. Questionnaire Design

From the 7Cs described in Section 2.1, key aspects of the urban environment that may influence walkability were selected from the referred literature. Twenty-nine (29) elements were selected and transformed into statements that reflected the possibility of them being barriers to the use of the urban space from the pedestrians' perspective. Words such as "a lot", "few", "adequate", "enough", and "sufficient" were used to express the individual and subjective conformity facing the elements. Furthermore, the use of statements describing tangible attributes were preferred compared to highly subjective measures. For example, instead of using "easy to cross the street", issues regarding the number of crosswalks and the unsafe perception while crossing the street due to conflicts with cars. To minimise biased answers, every survey had the statements presented in a random order to participants. Table 3 presents the statements created and evaluated in the survey. A number was randomly assigned to each statement to facilitate the presentation of the barriers on figures further presented. During this stage, there was an intention to balance the number of statements on each walkability dimension to obtain a good representation for all 7Cs.

Table 3: Statements form the survey

Dimensions	N°	Elements
Connectivity	29	Bus stops are not easily accessible (e.g., narrow spaces and obstacles such as steps).
		I do not feel motivated to walk, because
	15	there are many interruptions in the sidewalk (e.g., discontinuous sidewalks).
	16	there are few crosswalks on the street.
Convenience		**I do not feel motivated to walk, because**
	17	the sidewalk is too narrow.
	18	there are many obstacles on the sidewalk (i.e., poles, trash bins, electrical boxes).
	19	there are no services, shops or public facilities that interest me.
	20	many services, shops or public facilities are closed.
Comfort		**I do not feel motivated to walk, because**
	21	the street is too steep.
		I do not feel comfortable to walk, because
	11	vehicles are illegally parked on the sidewalk.
	12	vehicles are illegally parked on the street (e.g., on a traffic lane interrupting traffic flow).
	13	there are a lot of vehicles parked on the street.
	14	there is excessive air or noise pollution.
Conviviality		**I do not feel safe to walk, because**
	10	I am afraid of being mugged or violated.
		I do not feel motivated to use the public space, because
	28	there are few places to socialize (e.g., kiosks and outdoor tables).
		I do not feel motivated to walk, because
	22	urban furniture is inadequate (e.g., benches, trash bins).
	23	shading is insufficient (e.g., trees).
Conspicuity		**I do not feel safe to walk, because**
	1	the lighting is poor.
	2	there are few people on the street.
	3	there are too many people on the street.
	4	I have difficulty finding my way around the street (e.g., directional signs, landmarks).
Coexistence		**I do not feel safe to walk, because**
	5	there are many vehicles circulating in the street.
	6	drivers disrespect pedestrians' priority at crosswalks.
	7	vehicles travel at inappropriate speeds.
	8	vehicles drive very close to the sidewalk.
Commitment		**I do not feel safe to walk, because**
	9	I might slip or trip on the sidewalk
		I do not feel motivated to walk, because
	24	there is litter on the ground.
	25	the sidewalk is in bad condition (e.g., uneven pavement).
	26	there is visual pollution (e.g., graffiti, signs, billboards).
	27	it is difficult to access places I want to go.

Source: Author

3.4. Street Survey and Sampling

The street survey was conducted on June 25th, 26th, 27th, and July 4th, 2024, from 8 a.m. to 8 p.m., with breaks from 2 p.m. to 3 p.m. and from 5 p.m. to 6 p.m. Respondents were randomly selected and asked to give a dichotomous response (agree or disagree) to the statements presented in Table 3. It is important to emphasize that the respondents were instructed to answer their perception of the street at the time they were surveyed. Then, the answers were divided into three time periods that usually display different travel patterns: (1) inside peak hours (from 8 a.m. to 9 a.m. and from 6 p.m. to 8 p.m.), (2) outside peak hours (from 9 a.m. to 10 a.m. and from 3 p.m. to 5 p.m.), and (3) lunch time (an extended period from 10 a.m. to 2 p.m.). This aggregation was made considering the regular travel patterns observed on the street. To help with this aggregation, *Google Maps' Popular times* was used to capture how demand varies for some stores and services on Rua Morais Soares (Google, 2024). It uses aggregated and anonymised data from users that have *Google Location History* on. Additionally, socio-demographic information, such as age, gender, educational level, occupation, and country of origin, was collected.

Regarding sample sizing, Hagell & Westergren (2016) and O'Neill et al. (2020) suggest a minimum of 250 observations for good balance for statistical interpretation of the model. For this study, a minimum of 250 observations for each period was considered to allow the comparison between them. Moreover, the sample was sized in such a way as to approach the distribution of gender and age groups (under 25, between 25 and 64, and over 64) in Lisbon, in line with the latest Census (INE, 2021). Overall, a total of 1031 responses was obtained. Table 4 shows the descriptive statistics resulting from the survey.

Table 4: Descriptive statistics of the data obtained

Item	Subgroup	Sample	
Time Period	Inside Peak Hours	313	(30,4%)
	Outside Peak Hours	302	(29,3%)
	Lunch Time	416	(40,3%)
Gender	Male	414	(40,2%)
	Female	613	(59,5%)
	Non-Binary	4	(0,4%)
Age	< 25	206	(20%)
	25 - 64	561	(54,4%)
	> 64	264	(25,6%)
Occupation	Student	154	(14,9%)
	Business Owner	32	(3,1%)
	Employee	477	(46,3%)
	Self-employed	84	(8,1%)
	Retired	227	(22%)
	Unemployed	57	(5,5%)
Educational level	Elementary school	283	(27,4%)
	High school	359	(34,8%)
	Higher technical course	30	(2,9%)
	Bachelor's Degree	232	(22,5%)
	Master's Degree	94	(9,1%)
	Doctor's Degree	21	(2%)
	None	12	(1,2%)
Place of Birth	Portugal	726	(70,4%)
	Brazil	139	(13,5%)
	Europe (except Portugal)	60	(5,8%)
	Africa	52	(5%)
	Asia	38	(3,7%)
	Others (Australia, Americas, except Brazil)	16	(1,6%)
Most used transport modes	Walking	581	(56,4%)
	Private car (as driver or as passenger)	246	(23,9%)
	Public transportation (bus, metro, train)	830	(80,5%)
	Bicycle or E-scooter (owned or shared)	22	(2,1%)
	Taxi or Ride-hailing (Uber, Bolt)	75	(7,3%)
Do you live near Rua Morais Soares?	Yes	690	(66,9%)
	No	341	(33,1%)
Used to walk or use outdoor seating areas on Rua Morais Soares?	Yes	886	(85,9%)
	No	145	(14,1%)
Do you like to walk on Rua Morais Soares?	Yes	429	(41,6%)
	No	309	(30%)
	Neutral	293	(28,4%)

Source: Author

3.5. Modelling Perceptions of the Urban Environment

Rasch model (RM) belongs to item response theory (IRT), which applies a transformation to ordinal data turning it into a numerical scale measured in logits (log-odds units), to which parametric statistics can be applied (Cheng, 2010). It is a one-parameter logistic model, meaning item difficulty is assumed to be the only characteristic that influences the respondents' performance. Similar to regression models, IRT models estimate parameters from a dataset. However, unlike regression models, the independent variable is unobservable (Hambleton et al., 1991).

The RM measures the difficulty of the items tested b_i, that is their relevance as a barrier, and the respondents' ability θ_n to overcome these difficulties on the same interval scale. Together, the estimated parameters determine the pedestrian's probability of overcoming the items. The b_i parameter is the point on the ability scale where the probability of a pedestrian responding to an item correctly (*i.e.*, overcoming the barrier) is 0.5. That means the greater the value of b_i, the greater the ability required for a pedestrian to have a 50% chance of not considering the item as an obstacle (Hambleton et al., 1991). Figure 2 illustrates the conceptual model of the RM. In the example, both pedestrians A and B are not likely to overcome barrier 1, being that they are lower than the barrier itself in the scale. At the same time, pedestrian A is more likely to overcome barrier 2 than pedestrian B, as the former is higher in the scale.

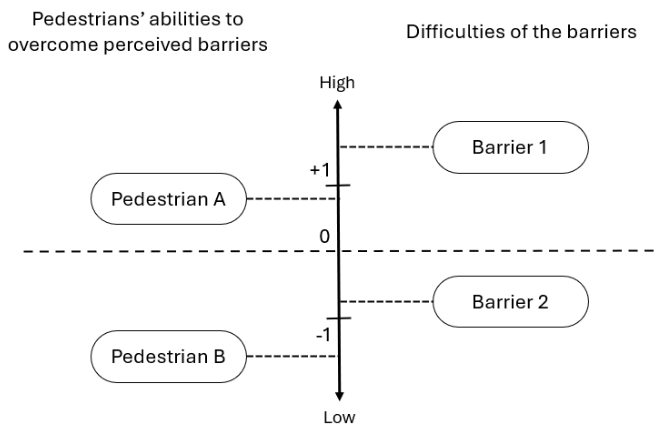

Figure 2: Illustration of the measurement concept of the Rasch model. Source: Author

The probability of person n overcoming item i is given by Equation 1 (Hambleton et al., 1991), where θ_n represents the ability of each person n and b_i, the difficulty of each item i. In the first iteration, the model generates the ability parameters from the survey's responses (that represents the degree to which respondents can overcome the barriers) and considering that respondents have 50% chance of overcoming them. The model converges to minimise the difference between observed abilities (pedestrians' responses) and expected abilities (generated from the difficulty of the items captured by the survey). Equation 1 is also known as the item characteristic curve (ICC), which express the probability of successfully responding to an item in relation to the respondent's ability.

$$P(1|\theta_n, b_i) = \frac{e^{\theta_n - b_i}}{1 + e^{\theta_n - b_i}} \tag{1}$$

Therefore, the log odds ratio is given by the subtraction of the two parameters estimated by the model (person and item parameters), as seen in Equation 2 (Hambleton et al., 1991), where $P(0|\theta_n, b_i)$ is the probability of person n not overcoming item i.

$$\ln \frac{P(1|\theta_n, b_i)}{P(0|\theta_n, b_i)} = \theta_n - b_i \tag{2}$$

Before running a RM, it is crucial to check whether the data meets the unidimensionality assumption, that is if only one ability is being measured by the survey. Despite, this premise is seldom fulfilled (Cheng & Chen, 2015; Hambleton et al., 1991). Exploratory factor analysis (EFA) is often used to assess unidimensionality (Tate, 2003), as it enables the identification of underlying constructs that summarise a dataset (Ford et al., 1986). To assess the model's fit statistics, infit and outfit measures are generated. It indicates how far the item fit is from the expected mean and standard deviation. While the former is more sensitive to deviations on items that are close to the person's ability, the latter is more sensitive to extreme deviations, or unexpected items, which are far from the person's ability. For example, if a person with an average ability level scores low on an item with average difficulty, infit will capture it with more intensity. If a person with low ability level scores high on a hard item, outfit captures this inconsistency with more intensity.

4. RESULTS AND DISCUSSION

4.1. Test reliability, consistency, and test of fit

First and foremost, EFA was performed on the data obtained to assess dimensionality. Results show that one first factor retains around 9% of variance, failing to comprise the recommended explained variance of 20% (Chang & Wu, 2008; Reckase, 1979). Violating unidimensionality means that model fit, validity, and reliability could be compromised (Reckase, 1979; Tate, 2003). Considering that the questionnaire was designed to represent the seven dimensions considered in the study (7Cs), EFA was applied separately in each dimension. Explained variance increased in all cases, ranging from 10% to 32%, but only *Conspicuous, Coexistence*, and *Comfort* presented values greater than or equal to 20%. Despite, the results were not deemed jeopardised because of model fit and consistency, which are further explored in this section.

To further understand the data structure, EFA was performed to retain two factors, which returned an explained variance of 13%. However, it is evident that the factors were generated according to item difficulty (*i.e.*, one factor had items with large parameters, and the other had items with small item difficulty), signalling that the results could be biased towards the estimated parameters. After analysing the scree plot and the eigenvalues obtained from the EFA, retaining four factors seemed to be adequate. In this case, total explained variance for the model raises up to 19%. Table 5 indicates the composition of these four factors and their factor loadings, which represent the variance of the items explained by each factor (Ford et al., 1986).

According to Ford et al. (1986), loadings lower than 0.40 are often considered not significant, which in the case of this current study could indicate that four factors poorly explain the data, as only nine out of the twenty-nine items have factor loadings greater than 0.40. From the analysis of the bigger loadings for each item, one can observe that factor 1 reveals the correlation between the items that consider parked vehicles. Factor 2 contains items related to safety, security, and pedestrian amenities (*e.g.*, furniture, shading, commerce, lighting, etc.). These barriers seem to trigger negative emotions on pedestrians. Factor 3 reveals physical obstacles to walking (*e.g.*, sidewalk width, obstacles, and condition, slope, etc.) and some kind of visual discomfort (*e.g.*, visual pollution, litter). At last, factor 4 is composed of four hard items to be overcome: traffic volume, tripping/slipping on the sidewalk, pollution, and the presence of many people on the street. While all three items are from the *Comfort* dimension for the first factor, the others present items from at least four different dimensions. Thereby, no clear correlation to the aggregation of items made in Section 3.3 was identified.

Table 5: EFA for 4 factors retained

Items	Factor loadings			
	F1	F2	F3	F4
VehiclesInLane	0.78			
VehiclesInSidewalk	0.76			
ParkedVehicles	0.49			
AccessibleBusStops		0.48		
OpenCommerce		0.47		
NonAccessiblePlaces		0.44		
Shading		0.34		
SidewalkContinuity		0.34		
SpacesForSocialising		0.31		
Lighting		0.30		
VehicleSpeed		0.28		
Orientation		0.26		
Security		0.25		
FewCrosswalks		0.25		
Litter		0.21		
Commerce		0.21		
SidewalkObstacles			0.58	
SidewalkWidth			0.49	
Slope			0.30	
VisualPollution			0.29	
Buffer			0.26	
Litter			0.22	
SidewalkConditions			0.21	
CrosswalkPriority			0.20	
FewPeople			0.13	
LotOfPeople				0.57
VehicleVolume				0.27
Pollution				0.22
SidewalkFall				0.17

Source: Author.

To validate internal consistency of the data, item and person reliability coefficients were generated. They can be interpreted similarly to Cronbach's alphas coefficient, which describes the extent to which the items in the survey measure the same constructs (Chang & Wu, 2008; Cheng, 2010). The values obtained are 1.00 and 0.70 for item and person coefficients, respectively. Results indicate data consistency (≥ 0.70), but a value larger than 0.90 suggests redundancies on the items assessed (Tavakol & Dennick, 2011).

Moreover, Table 6 shows the results of the goodness-of-fit test, indicating infit and outfit measures for all items. MNSQ are between 0.91 – 1.32, indicating a suitable fit (near 1), for both infit and outfit (Cheng & Chen, 2015). Regarding t-statistics, most values are between –2 and 2, which means model adjustments are not so different from what was expected. Values larger than 2 suggest that an item that was harder than expected or that it has an unpredicted variability (*e.g.*, shading, furniture, number of people on street). Values smaller than –2 can indicate that the item is too easy or too predictable (*e.g.*, illegally parked vehicles on street, traffic speed). This corroborates with the idea that besides the data not assuring unidimensionality, results were not significantly compromised and the model produced consistent results.

Table 6: Item fit statistics

Dimensions	N°	Item	Outfit		Infit	
			MNSQ	t	MNSQ	t
Connectivity	15	There are many interruptions in the sidewalk	0.96	-1.46	0.97	-1.16
	16	There are few crosswalks on the street	1.03	1.05	1.02	0.56
	29	Bus stops are not easily accessible	0.94	-1.24	0.97	-0.65
Convenience	18	There are many obstacles on the sidewalk	0.96	**-2.07**	0.97	-1.74
	17	The sidewalk is too narrow	1.00	-0.21	1.00	-0.02
	19	There are no services, shops or public facilities that interest me	1.03	1.45	1.02	1.10
	20	Many services, shops or public facilities are closed	1.01	0.14	1.00	-0.05
Comfort	13	There are a lot of vehicles parked on the street	0.92	-1.84	0.95	-1.03
	14	There is excessive air or noise pollution	0.95	-1.16	0.97	-0.69
	12	Vehicles are illegally parked on the street	0.91	**-2.36**	0.94	-1.57
	11	Vehicles are illegally parked on the sidewalk	0.95	-1.83	0.96	-1.56
	21	The street is too steep				
Conviviality	10	I am afraid of being mugged or violated	1.01	0.51	1.01	0.38
	23	Shading is insufficient	1.07	**3.53**	1.05	**2.78**
	22	Urban furniture is inadequate	1.05	**2.63**	1.04	1.98
	28	There are few places to socialize	1.03	0.98	1.01	0.44
Conspicuity	3	There are too many people on the street	1.12	**3.37**	1.04	1.20
	1	The lighting is poor	1.05	1.17	1.00	0.12
	2	There are few people on the street	**1.32**	**4.44**	1.08	1.13
	4	I have difficulty finding my way around the street	1.14	1.92	1.02	0.28
Coexistence	5	There are many vehicles circulating in the street	1.00	0.05	1.00	-0.04
	6	Drivers disrespect pedestrians' priority at crosswalks	0.99	-0.59	0.99	-0.55
	7	Vehicles travel at inappropriate speeds	0.96	**-2.25**	0.97	-1.80
	8	Vehicles drive very close to the sidewalk	0.96	-1.88	0.98	-1.18
Commitment	24	There is litter on the ground	0.99	-0.08	1.00	-0.02
	25	The sidewalk is in bad condition	1.00	-0.05	1.00	-0.01
	9	I might slip or trip on the sidewalk	1.02	0.59	1.01	0.33
	26	There is visual pollution	1.01	0.45	1.00	0.15
	27	It is difficult to access places I want to go	0.93	-1.50	0.96	-0.81

Source: Author

4.2. Item Difficulty and Person Ability

In this section, the results from the RM are presented. The subsections that follow explore how different groups perceive the elements differently. It is worth mentioning that these results are particular to the case study and does not represent a general ranking of urban attributes, although the questionnaire can be replicated to different locations. As stated in Section 2.1, walkability assessments are very context-oriented, being that there will be differences in the results obtained from different studies. However, the results presented represent not only to the identification of barriers and their difficulties, but also how they change in different periods.

4.2.1. Aggregated Data

Before disaggregating the data and analysing differences between subgroups, this section explores the item difficulties considering the dataset obtained during the whole day, as seen in Table 7. Results show that the dimensions that contain more hard items are *Comfort, Commitment* and *Coexistence*, while the dimensions that contain easier barriers to overcome are *Connectivity* and *Conspicuous.* The most difficult barriers to overcome according to pedestrians are the presence of litter on the ground ($b = 1.82\ logits$), traffic volume ($b = 1.63\ logits$) and on-street parked vehicles ($b = 1.53\ logits$). Both air/noise ($b = 1.39\ logits$) and visual pollution ($b = 0.88\ logits$) seems to be important factors. In addition, parked vehicles, both illegally on the traffic lane ($b = 1.27\ logits$) and on the sidewalk ($b = 0.83\ logits$), and the condition of the sidewalk ($b = 1.11\ logits$) are also considered difficult to overcome.

On the other end, orientation issues ($b = -2.14\ logits$), the presence of few people on the street ($b = -2.07\ logits$), and the accessibility to both places ($b = -1.63\ logits$) and bus stops ($b = -1.60\ logits$) are the easiest items to overcome. Moreover, items often used to describe walkable places, such as sidewalk width ($b = -0.16\ logits$), street slope ($b = -0.64\ logits$), and sidewalk continuity ($b = -0.85\ logits$) seems to be overcome more easily by pedestrians in the considered case study. A negative parameter indicates that respondents with the average ability score ($\bar{\theta} \cong 0\ logits$) have more than 50% of chance of overcoming the barrier. In this scenario, three explanations could be given: (1) these characteristics are not considered important barriers for people to walk; (2) these variables have good objective measures on this context, meaning that sidewalks are wide and continuous, and the street is not so steep; or (3) despite being narrow, non-continuous, and steep, pedestrians do not consider this characteristics as barriers to walk on the street. As a matter of fact, this study does not comprise a more refined method to explore the relation between perceptions and the physical elements. Thus, no causal relationship can be established.

Table 7: Item Difficulty for aggregated data

Dimensions	N°	Item	Difficulty (logits)	Std. Error
Connectivity	15	There are many interruptions in the sidewalk	-0.85	0.07
	16	There are few crosswalks on the street	-0.93	0.07
	29	Bus stops are not easily accessible	-1.60	0.08
Convenience	18	There are many obstacles on the sidewalk	0.32	0.07
	17	The sidewalk is too narrow	-0.14	0.07
	19	There are no services, shops or public facilities that interest me	-0.43	0.07
	20	Many services, shops or public facilities are closed	-1.34	0.08
Comfort	13	There are a lot of vehicles parked on the street	**1.53**	0.08
	14	There is excessive air or noise pollution	**1.39**	0.08
	12	Vehicles are illegally parked on the street	**1.27**	0.08
	11	Vehicles are illegally parked on the sidewalk	**0.83**	0.07
	21	The street is too steep	-0.64	0.07
Conviviality	10	I am afraid of being mugged or violated	0.00	0.07
	23	Shading is insufficient	-0.23	0.07
	22	Urban furniture is inadequate	-0.31	0.07
	28	There are few places to socialize	-0.99	0.07
Conspicuity	3	There are too many people on the street	**1.07**	0.07
	1	The lighting is poor	-1.25	0.08
	2	There are few people on the street	-2.07	0.10
	4	I have difficulty finding my way around the street	-2.14	0.10
Coexistence	5	There are many vehicles circulating in the street	**1.63**	0.08
	6	Drivers disrespect pedestrians' priority at crosswalks	0.36	0.07
	7	Vehicles travel at inappropriate speeds	0.16	0.07
	8	Vehicles drive very close to the sidewalk	-0.23	0.07
Commitment	24	There is litter on the ground	**1.82**	0.09
	25	The sidewalk is in bad condition	**1.11**	0.07
	9	I might slip or trip on the sidewalk	**1.11**	0.07
	26	There is visual pollution	**0.88**	0.07
	27	It is difficult to access places I want to go	-1.63	0.08

Source: Author

Table 8 shows person ability estimates for the subgroups that are not being further explored in the next sections. Regarding the educational level, no correlation with the parameter could be established, respondents with a master's degree and a high school diploma have a higher probability of overcoming the barriers, while people with no education and with a technical course degree have the least. Regarding occupation, unemployed and self-employed people appear to have greater abilities compared to business owners and retired people on the other end. The latter present the smallest parameter ($\theta = -0.103\ logits$), which can be explained by the age of participants of this category (further analysed on Section 4.2.3).

Table 8: Person ability for different subgroups

Item	Subgroup	Sample size	Person ability (logits)
Educational level	Master's Degree	94	0.083
	High school	359	0.061
	Doctor's Degree	21	-0.022
	Elementary school	283	-0.037
	Bachelor's Degree	232	-0.047
	Higher technical course	30	-0.067
	None	12	-0.177
Occupation	Unemployed	57	0.110
	Self-employed	84	0.091
	Student	154	0.058
	Employee	477	0.011
	Business Owner	32	-0.035
	Retired	227	-0.103
Use sustainable modes?	No	104	0.115
	Yes	927	-0.009
Regularly use the street?	No	145	0.114
	Yes	886	-0.015
Enjoy walking on the street?	Yes	429	0.125
	Neutral	293	0.090
	No	309	-0.247
Is your income enough?	Yes	231	0.139
	Neutral	195	0.080
	No	431	-0.085

Source: Author

Respondents that said they did enjoy walking on Rua Morais Soares had a greater ability level than the ones that said they did not. Similarly, pedestrians that revealed not having issues related to their income presented a greater parameter than the ones that did. Furthermore, people that often use sustainable transport modes (*i.e.*, walking, transit, bike) and people that regularly use Rua Morais Soares (*i.e.*, walking, using outdoor seating areas) have smaller ability levels if compared to people that do not. The fact that these people are not used to walk on the street may indicate that they do not pay much attention to the elements that were presented, hence not deeming them as barriers.

4.2.2. Time Periods

When considering the aggregation of data in three time periods, some variation on item difficulty can be observed, meaning that pedestrians perceive the changes on the urban environment and that it has an impact on their motivation to walk. Figure 3 shows item difficulties resulted from the RM for the different periods considered (inside peak hours, outside peak hours, and lunch time). Interestingly enough, off-peak is the period with the least number of difficult barriers, with an average difficulty parameter of $-0.077\ logits$. Besides parked cars on the sidewalk ($b = 0.96\ logits$), all the other items that are harder outside the peak hours have negative difficulty parameters (or very close to it). It supports the idea that pedestrians that walk for activities other than commuting – that commonly happens at off-peak hours – are less prone to face elements negatively.

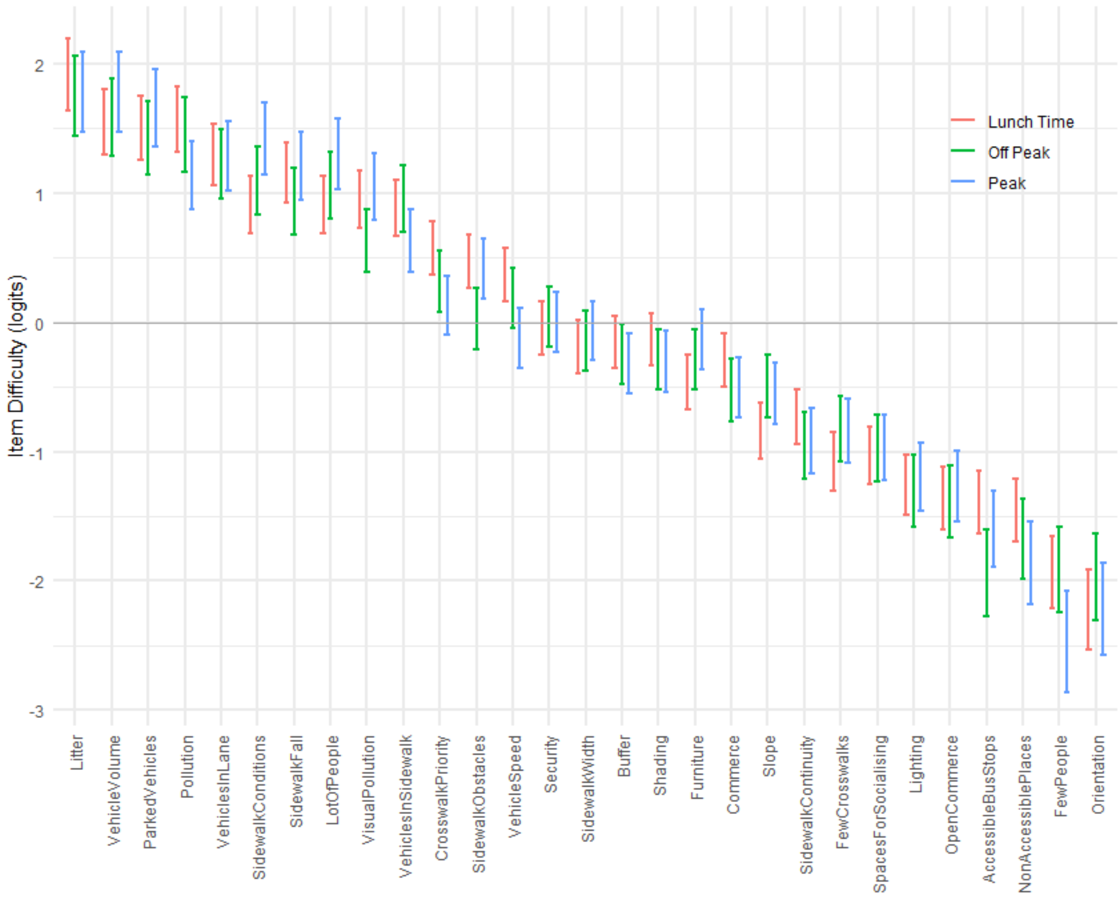

Figure 3: Item difficulty for different time periods ($CI = 95\%$). Source: Author.

At peak hours, sidewalk condition and presence of obstacles have found to be more difficult to be overcome by pedestrians. This could be explained by the fact that during this period, when people are mostly commuting, they want to quickly get to their destination (either home or work). Thus, physical obstacles tend to disturb pedestrian flow and annoy them. At the same time, people often like to chat with each other and enjoy their time outside during lunch time, possibly causing this variable to be easier then (although it is still the 8th hardest barrier analysed). Visual pollution appears to be seen as negative at peak hours as it is at lunch time, meaning that people also pay attention to urban aesthetics when commuting. Nevertheless, air/noise pollution can be highlighted as a barrier that is more difficult to be overcome at off-peak and at lunch time than at peak hours. It could be explained by the fact that the street's main role is related to the use of urban space during the periods that this barrier is harder. They usually represent periods that people are not commuting.

Other instigating items include the feeling of unsafety while using crosswalks and traffic speed, where it is possible to identify an increased difficulty at lunch time in contrast to the parameter at peak hours. One possible explanation could be that the increased number of vehicles at peak saturate the flow, decreasing traffic speed, hence not being considered as a barrier to pedestrians. While at lunch time and at off-peak periods, traffic volume tends to be smaller, increasing speed, causing the pedestrians to perceive it as being an obstacle to walking, hence creating a less safe environment to cross the street. However, it is important to reiterate that perceptions may be different from the objective measure. Even if traffic speed were lower during off-peak hours, people could still perceive it as a harder barrier during off-peak hours, because they are usually performing more leisure activities.

Similarly, the probabilities of pedestrians overcoming the barriers at peak hours are lower for almost every item, as shown on Figure 4, reaffirming that this period is the one that causes the most negative reactions. Pollution, vehicles parked on the sidewalk, crosswalk priority, and vehicle speed are the items that are most easily overcome at peak hours, in accordance with the analysis made based on item difficulty. At the same time, pedestrians overcome visual pollution and sidewalk obstacles more easily at off-peak periods. Considering lunch time, sidewalk condition and the presence of many people are the most easily overcome barriers.

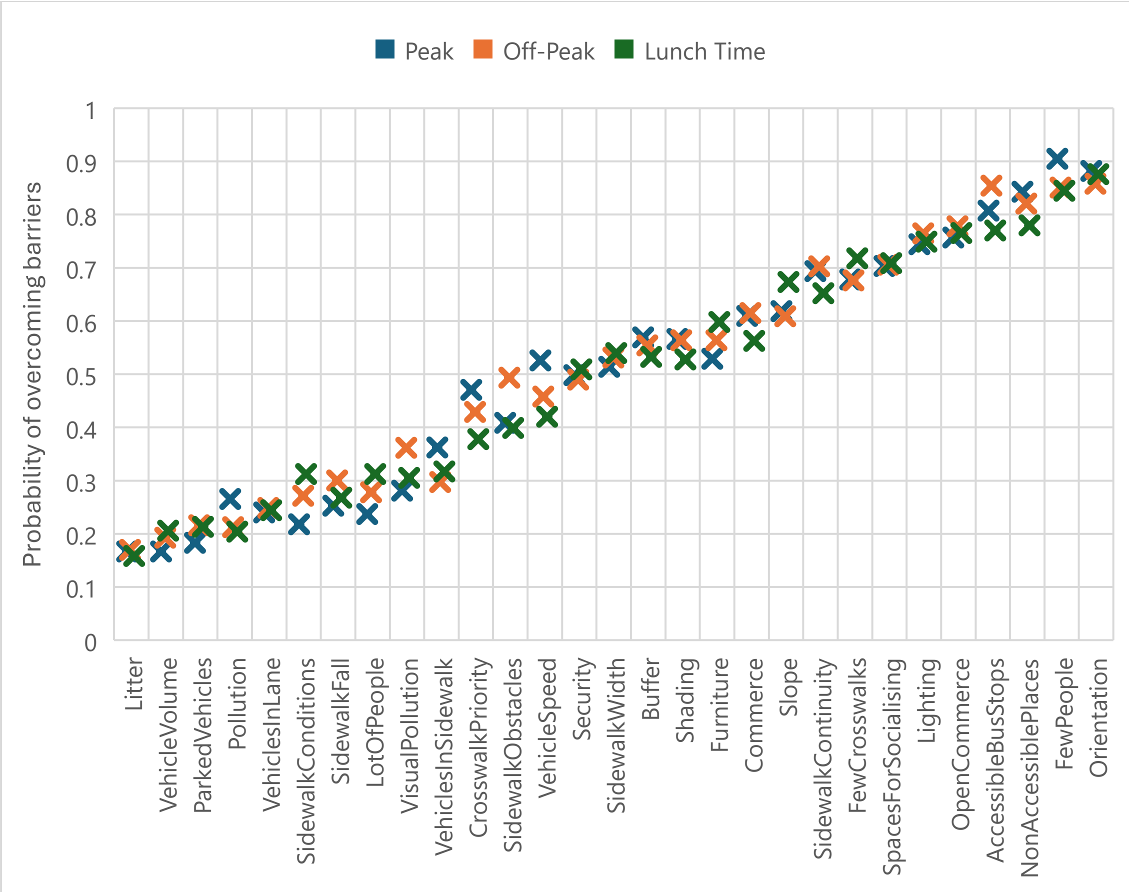

Figure 4: Probability of pedestrians overcoming the barriers. Source: Author

For analysing the distribution of respondents' abilities, person-item maps were generated (Figure 5 to Figure 7). They illustrate person ability on the same scale as item difficulty, enabling the identification of the number of pedestrians that can easily overcome the barriers. The figures below are marked with a red "M" and two blue "SD", indicating the range $[M - SD; M + SD]$, where *M* is for sample mean and *SD*, its standard deviation. The items are numbered according to Table 3. Person ability appears to have a stable behaviour. On all three cases, around 70% of respondents fall into this range.

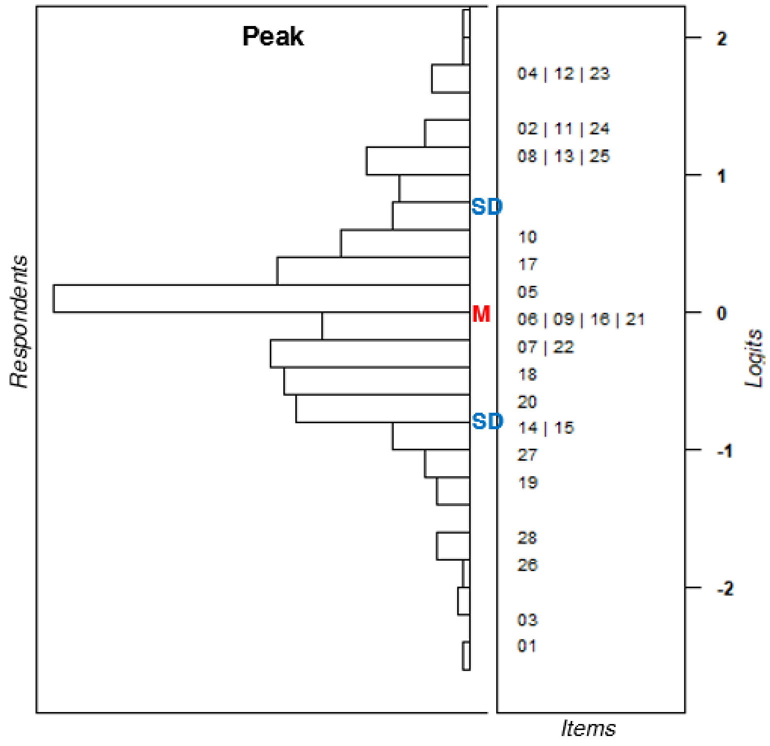

Figure 5: Person-item map at peak hours. Source: Author

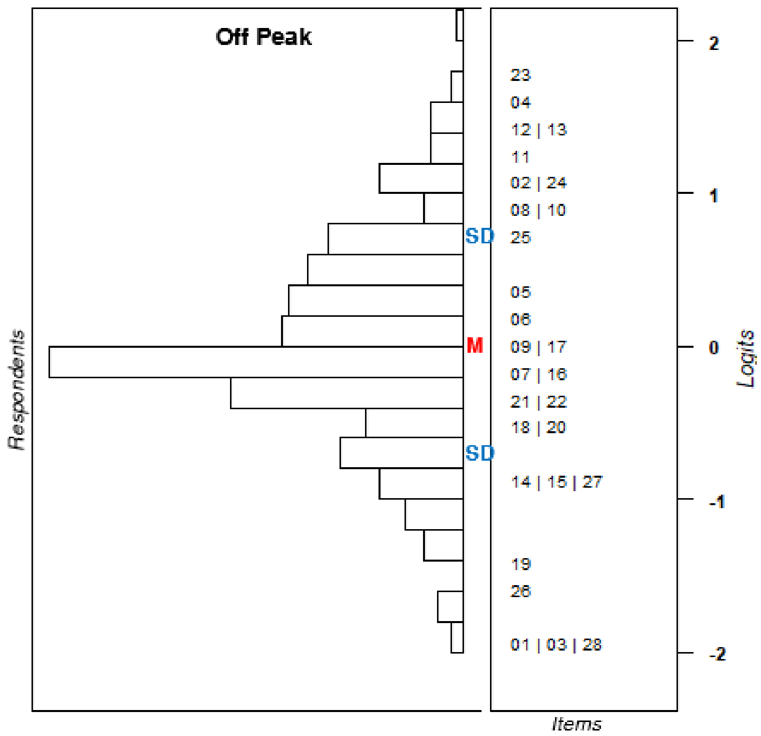

Figure 6: Person-item map at off-peak hours. Source: Author

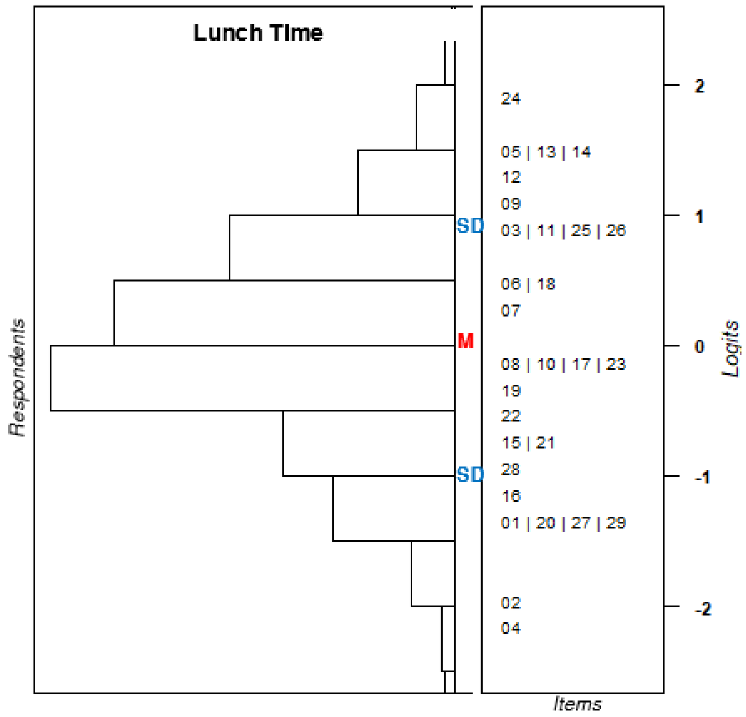

Figure 7: Person-item map at lunch time. Source: Author

Considering barriers with item difficulty $b \geq 0.5\ logits$, although the number of barriers is almost equal for all time periods (Table 9), the number of pedestrians overcoming the barriers with ease (*i.e.*, at least 50% of chance) doubles at lunch time if compared to peak hours, going from 13% to 26%. Off-peak hours also present a higher percentage (24%). This shows that more pedestrians face the elements as obstacles for walking at peak hours, which could also be noted by the larger item parameters on items on the $0.5\ logits \leq b < 1.0\ logit$ range, as seen in Table 9. Considering the hardest barriers (*i.e.*, $b \geq 1.0\ logit$), around 10% of respondents can overcome them with ease on all three cases.

Table 9: Item difficulty for items with $b \geq 0.5\ logits$

Item	Item Difficulty (logits)		
	Peak	Off-Peak	Lunch Time
Litter	1.78	1.75	1.91
VehicleVolume	1.78	1.58	1.55
ParkedVehicles	1.66	1.43	1.50
SidewalkConditions	1.42	1.10	0.91
LotOfPeople	1.30	1.06	0.91
VehiclesInLane	1.28	1.23	1.30
SidewalkFall	1.21	0.94	1.16
Pollution	1.14	1.45	1.57
VisualPollution	1.05	0.63	0.95
VehiclesInSidewalk	0.63	0.96	0.88
CrosswalkPriority	< 0.50	< 0.50	0.57

Source: Author

4.2.3. Age Groups

The results for different age groups reveal that people older than 64 years old are the most impacted by the barriers on the urban environment, being that they have an average difficulty parameter of $b = 0.078\ logits$. In comparison, youngsters (younger than 24 years old) have $b = -0.063\ logits$ and adults (between 24 and 64 years old) have $b = -0.093\ logits$. Out of the 29 elements, item difficulty for elderly is higher on 18 of these, while on only 2 for adults. Similarly, person ability parameters support the idea that older people ($\theta = -0.110$ logits) have more difficulty on overcoming the obstacles in comparison to adults ($\theta = 0.048\ logits$) and young people ($\theta = 0.028\ logits$). The higher the person parameter, the higher the probability of them overcoming the barriers.

Figure 8 shows the differences on item difficulty for the age groups considered. Elderly perceive more negatively variables related to safety and security, such as crossing priority ($b = 0.68\ logits$), traffic speed ($b = 0.48\ logits$), fear of being mugged or violated ($b = 0.36\ logits$), sidewalk condition ($b = 1.40\ logits$), and fear of tripping/slipping on it ($b = 1.45\ logits$). The presence of litter ($b = 2.50\ logits$) and parked cars ($b = 1.74\ logits$) are also harder for them to overcome. On the other hand, young people have more difficulty on overcoming attributes related to the quality of the environment, such as visual pollution ($b = 1.10\ logits$) and sidewalk width ($b = 0.19\ logits$) if compared to the other age groups. Furthermore, adults can more easily overcome barriers such as traffic volume ($b = 1.45\ logits$), pollution ($b = 1.26\ logits$), and the presence of litter ($b = 1.55\ logits$).

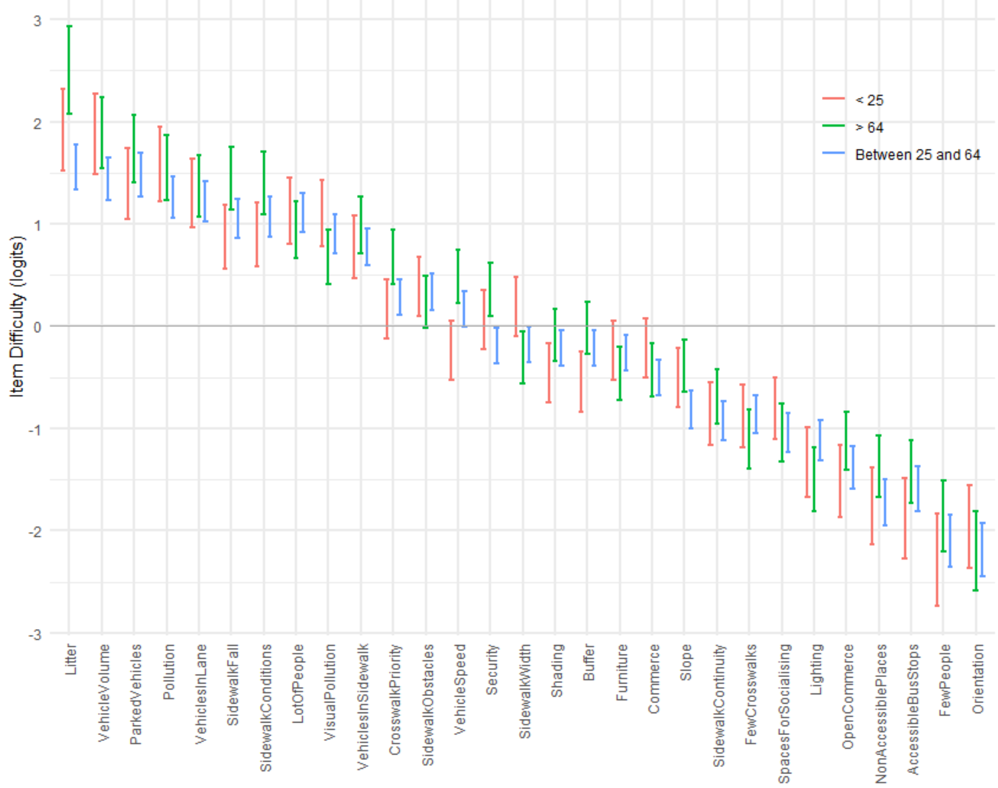

Figure 8: Item difficulty for different age groups ($CI = 95\%$). Source: Author.

4.2.4. Gender

Regarding gender, results show a significant difference between women's perceptions and men's (Figure 9). Twenty-six out of 29 variables are perceived as more difficult for women to overcome. Men have more difficulty on only three of them: the presence of few people on the street ($b = -1.73\ logits$), open commerce/services ($b = -1.25\ logits$), and difficulty on accessing places ($b = -1.56\ logits$), which are all items with low difficulty. The items with the most notable differences include security, traffic volume, parked vehicles, and pollution. The fear of being mugged/violated has the largest difference between genders, aligned with previous findings (Jahan et al., 2020). Results are illustrated on Table 10.

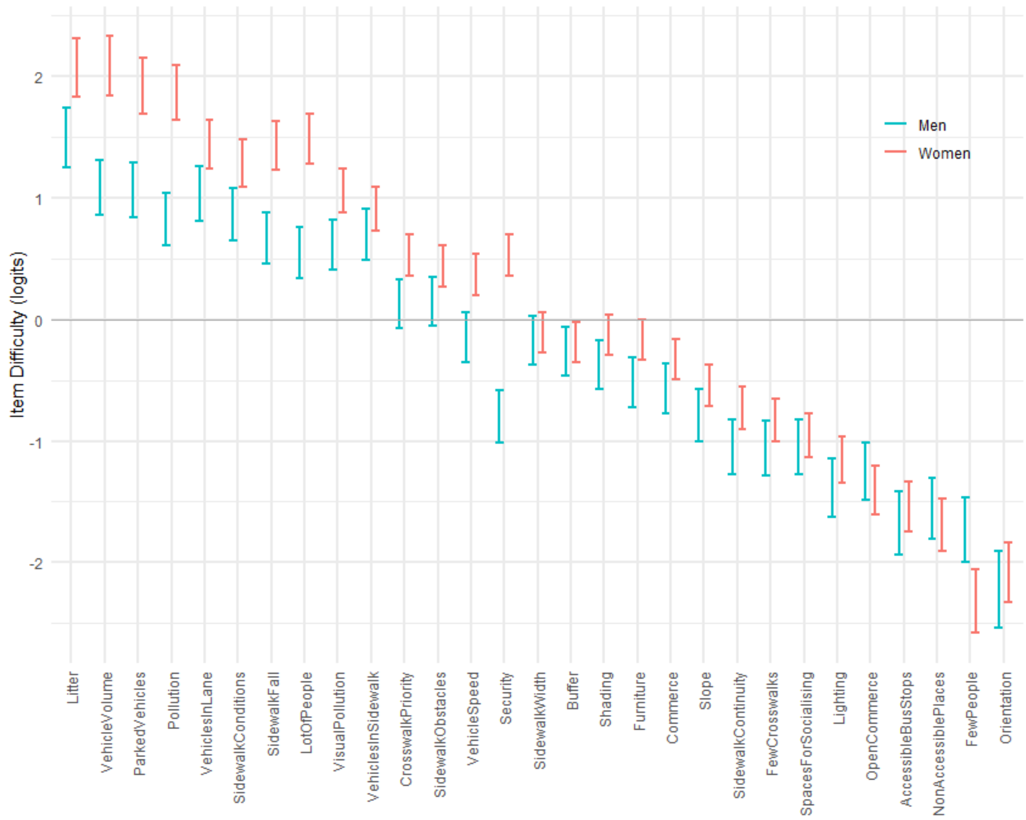

Figure 9: Item difficulty for men and women ($CI = 95\%$). Source: Author.

Table 10: Item difficulty regarding gender

	Item Difficulty (logits)				Item Difficulty (logits)		
	Men	**Women**	**|Men - Women|**		**Men**	**Women**	**|Men - Women|**
Security	-0.80	0.52	1.32	SidewalkObstacles	0.15	0.44	0.29
Pollution	0.82	1.87	1.04	Slope	-0.79	-0.54	0.25
VehicleVolume	1.09	2.08	0.99	Commerce	-0.57	-0.33	0.24
LotOfPeople	0.54	1.48	0.94	Shading	-0.37	-0.13	0.24
ParkedVehicles	1.06	1.92	0.86	FewCrosswalks	-1.06	-0.83	0.24
SidewalkFall	0.67	1.43	0.76	Lighting	-1.38	-1.16	0.23
FewPeople	-1.73	-2.32	0.58	VehiclesInSidewalk	0.69	0.91	0.22
Litter	1.49	2.07	0.57	OpenCommerce	-1.25	-1.41	0.16
VehicleSpeed	-0.15	0.37	0.52	Orientation	-2.22	-2.08	0.14
VisualPollution	0.61	1.06	0.44	AccessibleBusStops	-1.68	-1.54	0.14
SidewalkConditions	0.86	1.28	0.42	NonAccessiblePlaces	-1.56	-1.69	0.13
VehiclesInLane	1.03	1.44	0.41	SpacesForSocialising	-1.05	-0.95	0.10
CrosswalkPriority	0.12	0.52	0.40	Buffer	-0.27	-0.19	0.08
Furniture	-0.52	-0.17	0.35	SidewalkWidth	-0.17	-0.11	0.06
SidewalkContinuity	-1.05	-0.73	0.32				

Source: Author

4.3. Policy Implications

To reduce item difficulty, different policy measures can be implemented. However, any proposed change will likely face some resistance, because people tend to not accept measures that impact their habitual ways of living (*e.g.,* use of private cars) (Banister, 2000). Therefore, the involvement of people on the policy-making process is of the utmost importance, because the understanding of the rationale behind these policy changes helps with perspective shift and public acceptability. Plus, action will only take place when there is sufficient public support to drive political acceptability (Banister, 2008). In addition, policy measures are only indications of the scale and nature of change, the adoption of these measures is highly dependent on policy goals (Banister, 2000; Valença et al., 2024a).

Some variation in perceptions at different times of the day were identified in this study. The five most difficult items are the same for off-peak hours and lunch time: the presence of litter, traffic volume, air/noise pollution, and the existence of parked car, both on public parking and illegally on a lane The difference between time periods is the order of the second and third most difficult barriers (traffic volume and vehicle volume), as seen in Table 11. Regarding peak hours, relevant changes can be identified. Traffic volume, the presence of cars on on-street parking, and litter are still considered among the five hardest barriers. However, during this period, issues related to sidewalk condition and the presence of many people in the street are also considered important for pedestrian to walk. This means that people perceive the urban environment differently throughout the day, hence indicating the barriers can be tackled accordingly.

Table 11: Five most difficult barriers for each time period

Peak		Off-Peak		Lunch Time	
Item	b_i (logits)	**Item**	b_i (logits)	**Item**	b_i (logits)
VehicleVolume	1.78	Litter	1.75	Litter	1.91
Litter	1.78	VehicleVolume	1.58	Pollution	1.57
ParkedVehicles	1.66	Pollution	1.45	VehicleVolume	1.55
SidewalkConditions	1.42	ParkedVehicles	1.43	ParkedVehicles	1.50
LotOfPeople	1.30	VehiclesInLane	1.23	VehiclesInLane	1.30

Source: Author

Items such as the presence of litter, visual pollution, and sidewalk condition represent concerns related to how well-maintained the street is, hence indicating the need for a better engagement of local administration. For the last two issues, the removal of visual elements and the repair of the sidewalk can be proposed. Although they present differences on item difficulty on different time periods, their objective measures do not vary (*i.e.*, visual pollution and sidewalk condition are the same during the whole day), meaning they can be permanently addressed. Issues related to illegally parked cars can be tackled by increasing street surveillance/monitoring, especially outside peak hours, also reinforcing the need for the authorities' engagement. The perception of unsafe crossings can be addressed by adopting crossing aids, such as traffic control devices or traffic calming measures, such as speed humps, raised crossing or pinch points, which have the goal of reducing vehicle speed, creating safer crossings (Arellana et al., 2020; Talavera-Garcia & Soria-Lara, 2015; NACTO, 2016).

Some of the barriers identified can be addressed by reallocating urban space. This concept is presented as a way to increase the efficiency on the use of the available space, giving priority to active and collective transport modes, besides supporting the creation of a wider notion of the street, as a space not only for cars, but also for people. (Banister, 2000, 2008). More recently, Valença et al. (2021) proposed dynamically allocating road space, which consist of attributing different uses to the space on different times of the day, considering fluctuations on demand caused by land-use patterns and the location of activities on the territory. They highlight that it can also be beneficial in terms of public acceptance, being that the reallocation of space only in certain times of the day does not contest the car space when it is most critical (*i.e.*, at peak hours).

Both issues related to parked vehicles and pollution could be addressed by reallocating road space. Allocating public parking spaces to other uses, such as parklets, would objectively decrease the number of parked cars, although it would also decrease accessibility for some people. Reallocating traffic lanes to cycle or bus lanes, especially at off-peak and lunch time, would create incentives for using these modes instead of individual motorised vehicles, potentially tackling the problem of pollution and vehicle volume, in the long term.

To quantify potential improvements on service quality after adoption of some of these measures, a decrease in item difficulty is applied to the parameters resulted from the RM. This reduction on item difficulty leads to an increase in the number of respondents that have higher probabilities of overcoming the barriers. For example, if a given barrier have its difficulty decreased from $b = 1.0\ logits$ to $b = 0.5\ logits$, respondents with an ability level θ in the range $[0.5\ ; 1.0]\ logits$ start to have more than 50% of chance of overcoming the barrier. It is worth noting that the number of people overcoming the barriers is underestimated on this study, because once item difficulty decreases, person ability increases, as one parameter is estimated based on the another. Thus, more people would be able to overcome it. In this case, the original ability parameters were used to simplify the analysis. Figure 10 to Figure 12 illustrate improvements of different magnitudes (0.25, 0.5, 0.75 and 1.0 *logits*) on selected items and the percentage of pedestrians that can easily overcome them (*i.e.*, at least 50% chance) for the three time periods considered.

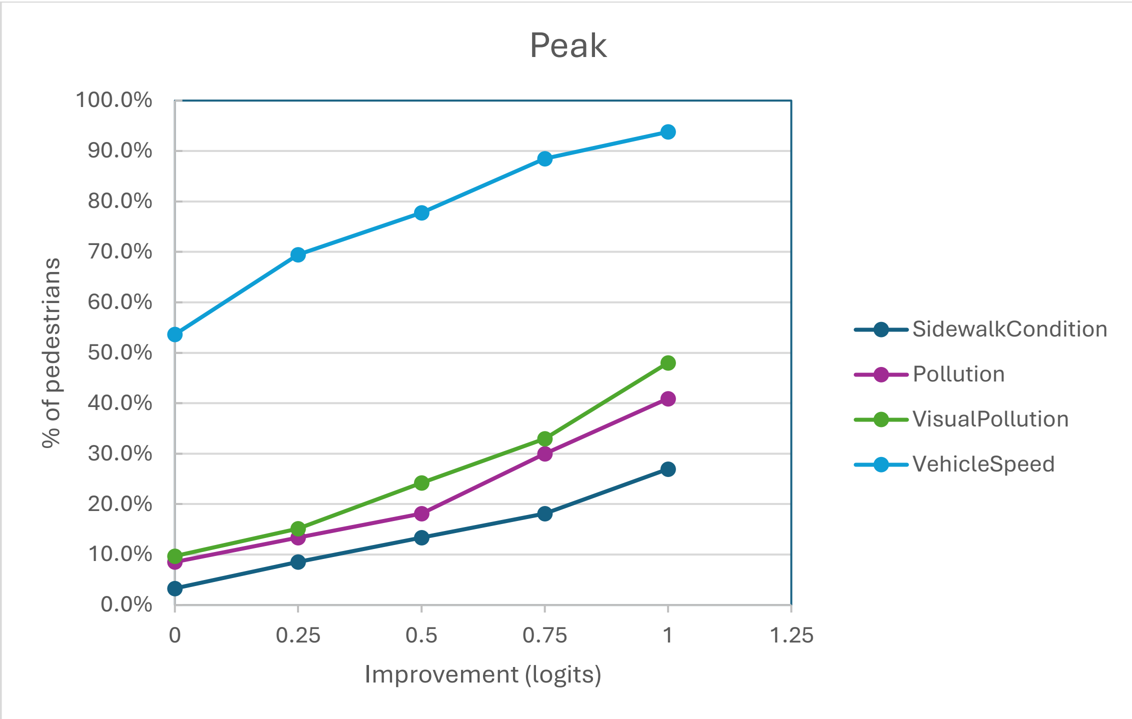

Figure 10: Relationship between improvement magnitude and the percentage of pedestrians overcoming barriers at peak hours. Source: Author.

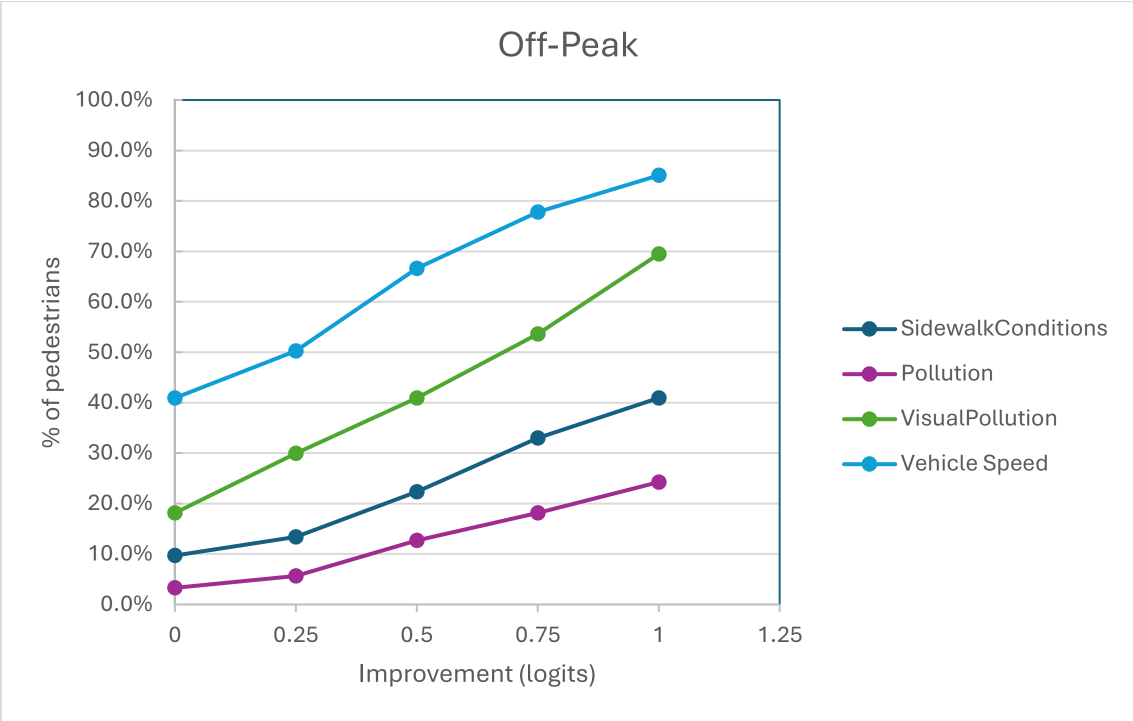

Figure 11: Relationship between improvement magnitude and the percentage of pedestrians overcoming barriers at off-peak hours. Source: Author.

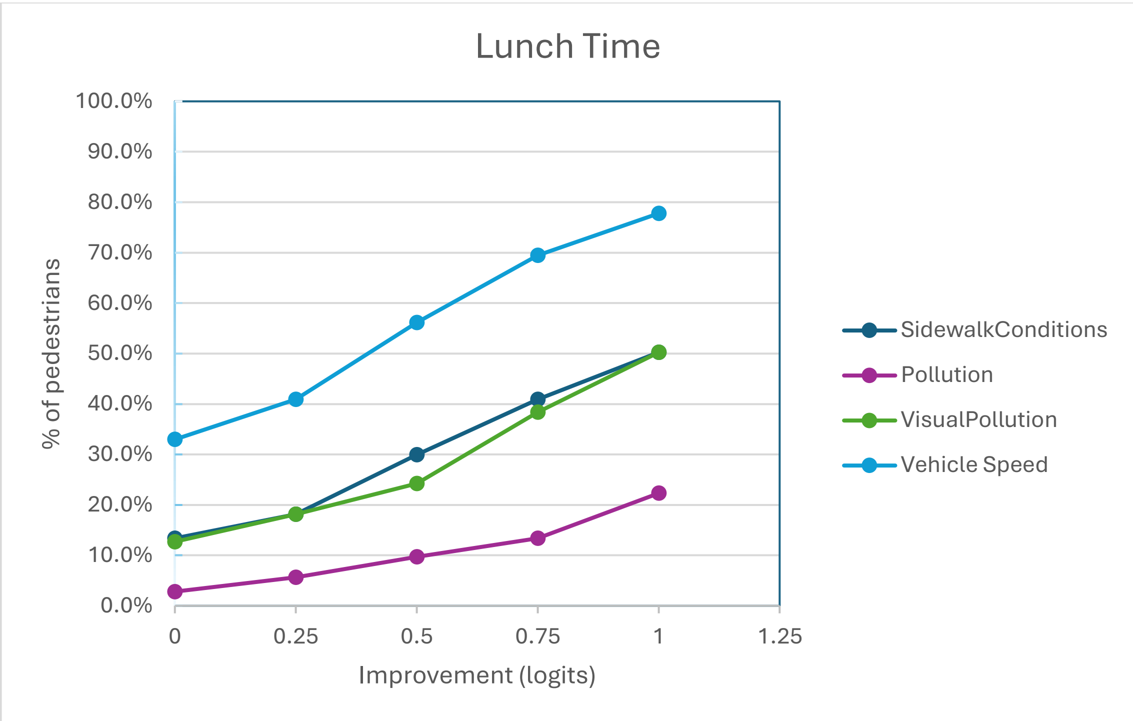

Figure 12: Relationship between improvement magnitude and the percentage of pedestrians overcoming barriers at lunch time. Source: Author.

Results show that decreasing vehicle speed could lead to almost 80% of pedestrians overcoming the item with ease at lunch time (when it is the hardest) with a decrease of 1.0 logit (from 33% on the current scenario). At peak and off-peak hours, it could reach 94% and 85%, respectively. Regarding pollution, around 50% of pedestrians would overcome this barrier with the removal of visual elements at peak and lunch time, almost reaching 70% outside peak. Decreasing air/noise pollution levels could cause a 10 times increase (from 2% to 22%) in the percentage of pedestrians overcoming it at lunch time.

5. CONCLUSION

Differences on travel demand indicate that the urban space can be used differently throughout the day. This study was able to identify how these fluctuations affect pedestrians' perceptions of the environment, indicating that urban attributes can be faced differently depending on the time of the day and on pedestrian type (*e.g.*, age, gender). It means that public policies can be elaborated to address the barriers identified on certain hours. Hence, the adoption of corrective measures increases the probability of pedestrians overcoming these barriers, and also increasing pedestrian's perceived walkability.

A Rasch model was applied on the data obtained by the survey, ranking the barriers by difficulty level. Regarding the aggregated data, the most difficult items were the presence of litter and parked vehicles (both on public parking and illegally on the lane), traffic volume, air/noise pollution, and sidewalk condition. *Comfort, Commitment* and *Coexistence* were the dimensions that presented the most difficult barriers, while the ones with the least are *Connectivity* and *Conspicuous*. Besides, some pedestrian variables, such as age and gender, appear to affect how they perceive the elements. For example, it is evident that the elderly have more difficulty on overcoming barriers related to traffic safety and sidewalk conditions. At the same time, men seem to find it easier to overcome the obstacles presented on the urban space compared to women.

After aggregating the dataset into the three periods considered (peak, off-peak, and lunch time), some variation on perceptions was observed. At peak hours, two of the five most difficult barriers are different from the ones observed at off-peak and lunch time. For the former, sidewalk condition and the presence of many people have a larger importance for pedestrians than at off-peak and lunch time. For the other two periods, besides traffic volume, the presence of litter, and parked cars – which are also presented at peak hours – issues related to air/noise pollution and illegally parked cars on lane are identified. Moreover, the items that present more changes during the day are pollution (air/noise and visual), sidewalk conditions and obstacles, crosswalk priority, and traffic speed. It is worth reiterating that fluctuations on perceptions may represent an objective change of the urban environment or not. For example, despite visual pollution being considered easier to overcome at off-peak hours, it does not necessarily mean that there are fewer visual elements during these periods, but that they are not perceived as negatively as in the other periods.

When analysing the distribution of person abilities, it becomes clear that pedestrians have less difficulty on overcoming barriers at lunch time and at off-peak hours. The percentage of pedestrians overcoming those with item difficulty $b_i \geq 0.5\ logits$ doubles at lunch time (26%) and almost doubles at off-peak (24%), compared to peak hours (13%). Therefore, the changes that occur on the urban environment are perceived by pedestrians and it affects their motivation to walk, meaning that public policies can be elaborated to tackle the issues identified on different times of the day. Nevertheless, some barriers that present variation on item difficulty can be addressed permanently being that it seems more logical to do so (*e.g.*, the removal of visual elements).

Despite successfully fulfilling this study's objectives, it has some limitations. First, it does not address the relationship between pedestrians' perceptions and objective elements. Future research can be developed to compare objective and subjective variables to better understand their correlation, as these measures can be misaligned (Gebel et al., 2011). In addition, the lack of empirical observations about pedestrian travel patterns generates uncertainties regarding the estimation of the time periods chosen. Data such as pedestrian volume could be used to better define these periods. Another limitation pays regard to user's point of view. The focus of this study was on pedestrians' perceptions, but they are not the only users of the street. Because the survey was applied on site, mobility impaired citizens, cyclists, and drivers are not well represented in the sample collected. Further work can evaluate urban attributes from different perspectives, exploring in more depth conflicts between transport modes.

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