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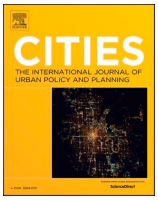

Age-friendly cities and active mobility: A thematic analysis based on immersive 360-degree video elicitation

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ABSTRACT

Public outdoor spaces in cities need renovation to accommodate new mobility forms and attend an ageing population. The quality of public spaces is rarely assessed, and when it is, it typically relies on post-occupancy methods that have marginal impact. Incorporating older adults' perceptions during the design phase to influence public space development is even less common. Digital technologies, such as virtual reality (VR) simulations, can provide innovative ways to engage older adults, understand their perceptions of public spaces and active mobility, and collect valuable data to guide design decisions and mitigate physical and safety risks.

This study explores how older adults perceive different types of streets in Lisbon. Using spherical videos and Head-Mounted Displays (HMDs), participants over 60 years old experienced four distinct urban settings, simulating short afternoon walks in pedestrian areas. Data were collected through think-aloud and interview protocols and analysed using thematic analysis. The findings, structured into four main themes and twenty-five subthemes, offer a general representation of Lisbon's streetscapes, capturing key physical features and perceptions applicable across various street types.

Supporting active mobility for traffic safety and sustainability, older adults highlighted the need for structural adjustments for inclusive accessibility. The quality of public space is associated with pavement materials, legibility, and separation of pedestrian and cycling areas through curbs, furniture, and trees, considered fundamental attributes for achieving appropriate streetscapes for multigenerational and inclusive spaces. This study demonstrated that immersive simulation media is feasible, inclusive, and engaging method for assessing perceptions, enabling older adults to contribute to the creation of dynamic, sustainable, and age-friendly cities.

1. Introduction

As societies age and life expectancy increases, adapting public spaces in cities to accommodate older individuals is a present urgency. By 2050, United Nations (UN) predicts that 16 % of the global population will be aged over 65, compared to 9 % in 2019 (UNFPA, 2019).

The growth of urban areas and cities is a global phenomenon, and it is where most of this group will be living. The United Nations (UN) predicts that by 2050, two out of every three people will likely reside in cities or urban centres. Aware of it, UN launched the "Global Age-Friendly Cities: A Guide" (2007) to encourage cities to become more age-friendly, highlighting the needs and opportunities to enhance the quality of life for ageing populations by addressing issues related to housing, transportation, healthcare, and public spaces.

Given the ageing demographics of the population and the inadequacy of urban public spaces, investigating the relationship between pedestrians and public spaces emerges as a vital element in understanding the attributes of public space for policy formulation (Fadda et al., 2010; Scott, 2021). Creating more inclusive, safe, and pleasant urban spaces (WHO, 2007) in equally secure, sustainable, and dynamic cities (Gehl, 2010) involves preparing cities' public spaces and ensuring pedestrian accessibility and safety. Consequently, factors such as appropriate materials, geometries, and signage contribute to comfort and a well-being-promoting experience while walking in the city.

The failure of accessible public spaces for older people is partly due to the reduction of pedestrian areas to accommodate new mobility modes. However, the shift of urban mobility through bicycles, scooters, and walking is arising due to benefits, such as promoting physical activity and leveraging less polluted and sustainable environments. It encourages public space utilisation on a more human-centred scale, rather

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than being solely focused on cars and streets, as advocated by authors like Gehl (Gehl, 2010) and Jacobs (Jacobs, 1963).

Studies indicate that poor-quality pedestrian areas (Zandieh et al., 2016), narrow sidewalks (Hennah et al., 2021), uneven pavements (Strohmeier, 2016), lack of resting places (Michael et al., 2006), and inadequate lighting (Bonaccorsi et al., 2023) are attributes of public urban areas that discriminate against senior populations from walking in public spaces.

Additionally, recent studies evaluate how the built environment impacts the senior's perceptions. Neighbourhood public areas, parks and streets, feature in studies assessing perceptions such as social cohesion (Mazumdar et al., 2018), fear of falling (Curl et al., 2020), and safety (Zandieh et al., 2016).

Therefore, it is evident that there is a demand to investigate the quality and adaptability of public spaces to the requests of older individuals from an architectural perspective. Most of these studies originate from fields such as health (Blackwood et al., 2022; Stearns et al., 2023), physical education (Rantakokko et al., 2010), and sociology (Caldwell et al., 2019). Despite the availability of this literature, we face a lack of research on the perceptions of older individuals regarding the attributes of the built environment in cities and new mobility groups.

The reported study was developed in Lisbon, Portugal, a city that experiences significant population ageing. In 2021, 23.4 % of the population in Lisbon was aged 65 or older. To promote active mobility, Lisbon launched a cycling (Presidência do Conselho de Ministros, 2019), and a pedestrian mobility (Presidência do Conselho de Ministros, 2022) strategies. Aligned with the ongoing transformation of the urban landscape, which includes the addition of cycling lanes and the adoption of new mobility devices such as scooters and electric bicycles, our study aims to describe the current urban context considering Lisbon's landscape.

Recently, the incorporation of segregated cycling lanes in the city, along with the implementation of bike-sharing systems, has led to a 3.5-fold increase in bicycle usage in Lisbon (Félix et al., 2020). Considering the adoption of bicycles as a mode of transportation, urban planners are prioritising the development of bike-friendly infrastructure.

This study investigates how older adults perceive the quality of public spaces, with particular attention to the role of active mobility. The primary research question focuses on their perceptions of pedestrian and cycling spaces. To develop a broader understanding of streetscapes in Lisbon, four different street typologies were selected. These were digitally reproduced using 360° video recordings and experienced by participants through immersive simulations with Oculus Quest headsets. Participants, all over the age of 60, engaged in semi-structured interviews following the simulations, allowing us to explore their experiences and insights within a controlled, yet realistic, experimental framework. Next, we developed a thematic analysis (Braun & Clarke, 2006), a well-established and rigorous qualitative method for identifying, analysing, and reporting patterns (themes) within data. Using this methodology enabled us to convert raw data to meaningful insights through an iterative process of familiarisation, coding, and theme development employed in recent urban studies (Barrantes-Chaves, 2024; Elliott et al., 2024; Finlay et al., 2023; Morea & Sabatini, 2023).

We seek to answer two research questions: 1) Are there identifiable patterns of relationships between street profiles with active mobility and the perceptions of older adults? 2) In which ways does Virtual Reality (VR) serve as applicable technology for simulating the built environment when older adults are the experimental subjects?

With this study, we aim to assist in decision-making within the scope of public policies targeting to promote age-friendly cities and active mobility. Urban planners, architects, designers, ergonomists, and researchers of public spaces benefit from this approach, which serves to understand urban attributes and guide pathways for adaptations in future interventions focused on active mobility.

2. Methodology

2.1. Case studies

Inspired by the streetscape audit protocol, validated by Kim and Lee (Kim & Lee, 2022), we selected four distinct streetscapes in central Lisbon, hereafter referred to as follows: Entrecampos (streetscape 1), Praça de Londres (streetscape 2), Avenida do Brasil (streetscape 3), and Avenida Duque de Ávila (streetscape 4), indicated on the map in Fig. 1. (See Figs. 2–5.)

The four selected streetscapes have architectural attributes presented in Table 1. The criteria for choosing these spaces were the presence of active mobility (pedestrian and cycling paths) and the presence of different configurations of pedestrian spaces and their relationship with cycling and road spaces. The four spaces differed in terms of street and sidewalk geometry, dimensions, and the relationship between pedestrian walkways, cycling paths, and pavement type. These four streetscapes are representative of the typologies chosen for the analysis, i.e., the relations that occur between pedestrians and cycling lanes with a focus on pedestrians. All four streetscapes have pedestrian sidewalks and cycle lanes in all four the relation with the cycle lane differs: Entrecampos (streetscape 1) – coexistence zone/mix use; Praça de Londres (streetscape 2) - cycling lane separated from the pedestrian lane by trees and in a lower level; Avenida do Brasil (streetscape 3) - cycling lane next to the pedestrian lane and in the same level; and Avenida Duque de Ávila (streetscape 4) - cycling lane separated from the pedestrian lane by trees, both are on the same level.

The designations mentioned in Table 1 adhere to the criteria established in the manual for public space published by the Lisbon city council (Câmara Municipal de Lisboa, 2018) to reach coherence in space classifications. In addition to spatial attributes, the selection of spaces considered neighbourhoods with higher longevity indices and a significant number of single-family residences inhabited by older adults (Camara Municipal de Lisboa, 2017). Spaces 1 and 4 are located in the Alvalade district, which has the highest longevity index and the largest number of adults aged 75 or older in the city.

The cycling spaces are classified into three distinct typologies: cycling lane (separated from the sidewalk by curbs), cycling path (visually separated from sidewalks by road markings on the pavement), and shared zone (Câmara Municipal de Lisboa, 2018).

The sidewalks predominantly feature Portuguese typical pavement, composed of pieces of cobblestone (da Silva & Pereira, 2022) with dimensions ranging from 4 to 11 cm. Although common in many pedestrian spaces in Lisbon, it creates a surface that is uncomfortable and unsafe for older adults (Pinto et al., 2020).

To enhance the immersive experience, we selected routes with the flattest terrain possible. Figures and 5 illustrate the typology and dimensions of the streetscape spaces used following the site attributes provided in Table 1. The label “OBS” (observer) represents the observer's position in the experience.

2.2. Experimental design

The methodology used in this study is within-subjects. This means that all participants were exposed to all four conditions – streetscapes - of the experiment. The experiment involved a walk simulation using videos with omnidirectional, 360° videos, creating an architectural narrative (Coates, 2012; Psarra, 2009).

The immersive experiences were conducted with 18 participants in five distinct spaces in Lisbon. A local community centre, a public library, and the university lab were selected based on their ability to meet the minimum requirements of providing a comfortable chair and maintaining a low noise level.

Fig. 6 shows images captured from the 360° videos of each streetscape, as well as the direction in which the experience progressed (other images can be found here https://github.com/mebfo/ThematicAnalysis

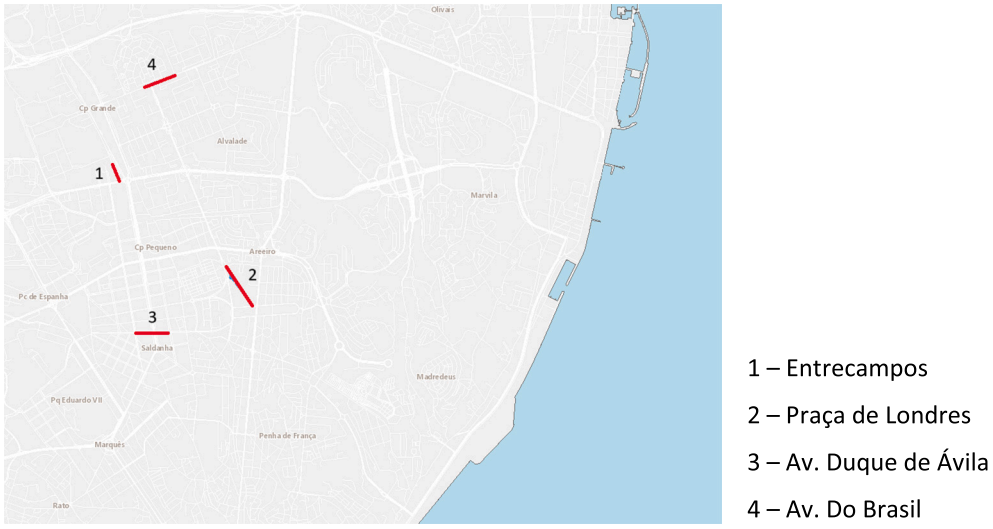

Fig. 1. Lisbon studied areas.

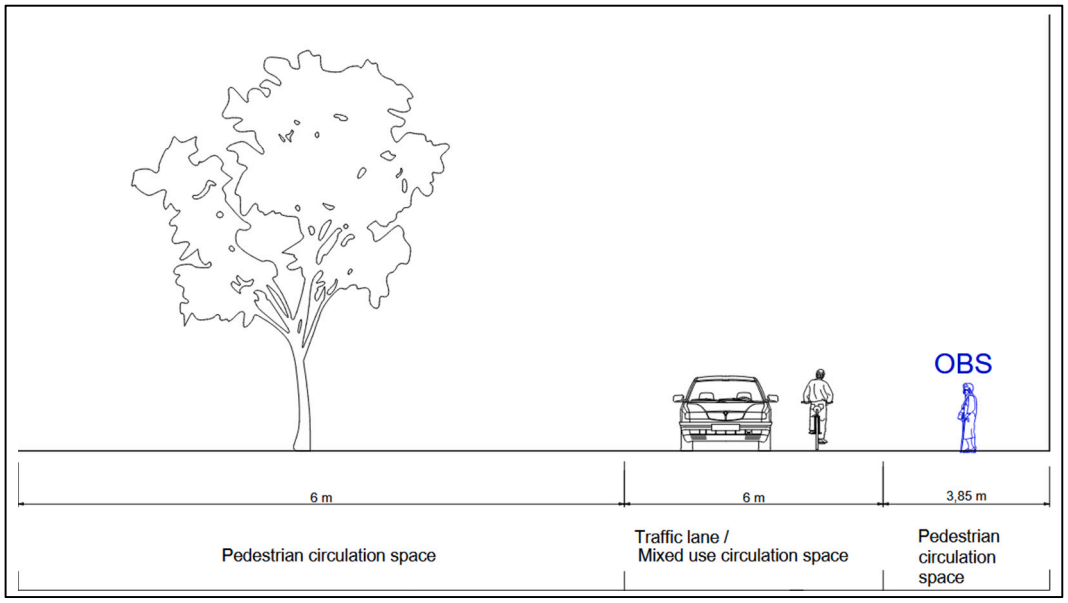

Fig. 2. Entrecampos (streetscape 1).

Lisbon360). The sequence between the four streetscapes was alternated to mitigate potential biases associated with the order of the presentation. Since the experience involved observing people's perceptions during immersion, participants were encouraged to observe the spaces freely in all directions, even though the path progressed unidirectionally. The experience was presented as a short walk during an afternoon period, without a specific purpose for utilitarian or leisure walking.

The extensions of the pathways reproduced in each of the four streetscapes range distances between 60 and 210 m, according to the average ordinary walks of older people (Gehl, 2010; Yung et al., 2016).

The walking direction in all cases followed the sidewalk, except at Entrecampos (streetscape 1), which is a coexistence zone. In such zones, all modes of transport - pedestrians, cyclists, and motor vehicles - share the same space to reduce car dominance and encourage walking and cycling (Karndacharuk et al., 2014). As a result, there was no requirement for pedestrians to remain on the sidewalk. During the experiment at Entrecampos, the walking path included crossing shared spaces, involving potential interactions with cars. In Avenida Duque d'Avila (streetscape 4) the participant crossed a pedestrian crossing between the two sidewalks. All videos depicted similar urban activity, including pedestrians, bicycles, scooters, and car traffic.

2.3. Experimental settings

The 360° footages of the streetscapes were captured between April 12 and May 05, 2023, between 1:00 and 4:30 PM, for consistent and uniform lighting. A camera LG R105 with a resolution of 2 K (2560 × 1280 pixels) was used to record simultaneously video and sound. Image quality created no problems with the users, who reported a good level of feeling of presence.

The capturing of the 360° videos was done in fixed locations at equal intervals, following the approach of Kim and Lee (Kim & Lee, 2022) protocol. Recording points were in the central line of the sidewalk, with an average interval of 10 m between each recording, lasting approximately 10 s, resulting in a walking speed of 1 m/s speed, an average for a 70 years individual (Buchmueller & Weidmann, 2007).

Each of the four final immersive videos was composed of the video sequences captured (see Table 2). The sequences were created using

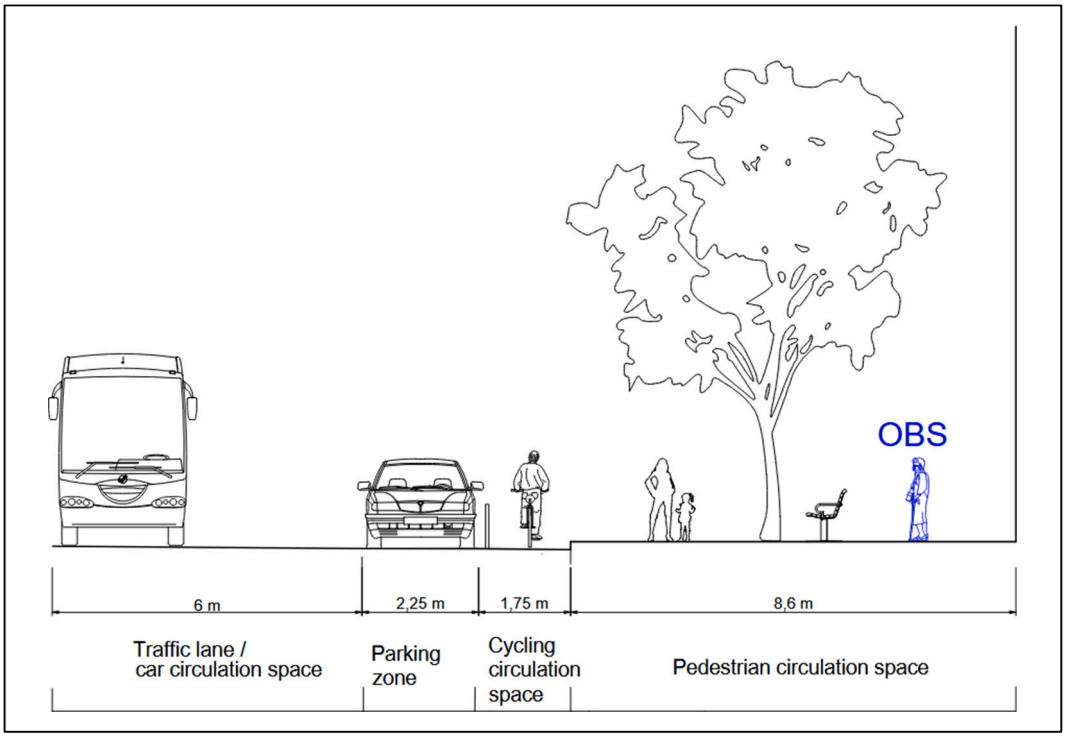

Fig. 3. Praça de Londres (streetscape2).

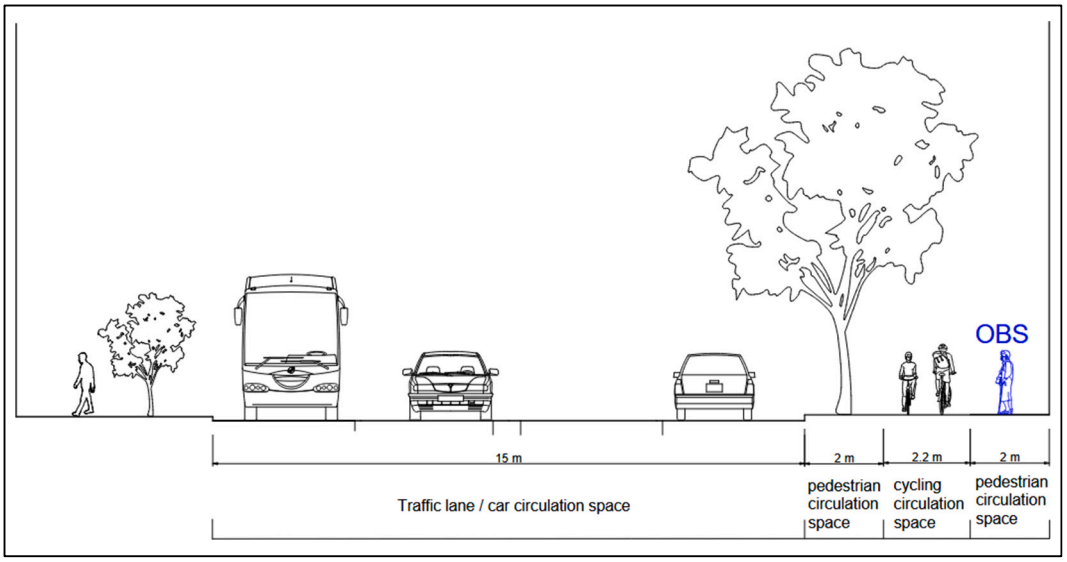

Fig. 4. Avenida do Brasil (streetscape 3).

DaVinci Resolve 19. To ensure optimal viewing on a Head-Mounted Display (HMD), the experience was integrated using the Unity game engine. Using the HMB enabled participants to look in any direction within the videos.

The simulated walking speed was approximately 1 m/s, following the average speed indicated in studies by Buchmueller and Weidmann (Buchmueller & Weidmann, 2007) and Daamen (2004). The walking simulation was conducted by adjusting the camera position approximately every 10 m and providing the user with a new viewpoint for observation and analysis every 10 s. This approach follows the methodology of Kim & Lee. Therefore, participants virtually moved at a constant speed across the four streets throughout the experiment, providing a uniform experience.

During the experiment, participants used a head-mounted display (HMD), Oculus Meta Quest 2, selected due to its suitability for spherical video observation. Its field of view, measuring 90° x 90°, enables an immersive experience by allowing participants to contemplate the virtual environment as if they were 'present' (Weber et al., 2021). Although the human field of view (FOV) is 180 × 120 (Panero & Zelnik, 2014), studies indicate that the provided FOV induces a sense of presence (Jicol et al., 2023).

The posture adopted by participants during the activities was seated in a fixed chair, as reported in similar studies (Schwind et al., 2019; Vilar et al., 2014). The total duration of the entire experience ranged from 20

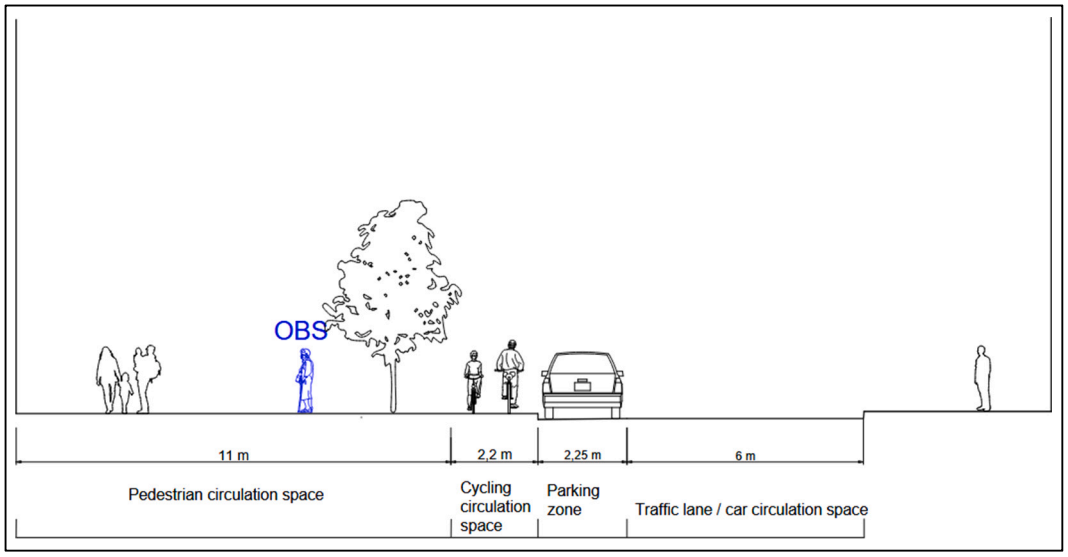

Fig. 5. Avenida Duque de Ávila (streetscape 4).

Table 1
Architectural attributes from studied spaces, adapted from (Câmara Municipal de Lisboa, 2018).

	Entrecampos (streetscape 1)	Praça de Londres (streetscape 2)	Avenida do Brasil (streetscape 3)	Avenida Duque de Ávila (streetscape 4)
Cyclable Route Typology	Coexistence zone	Cycling Lane unidirectional counterflow, protected by parked vehicles	Cycling Path bidirectional raised to curb height	Cycling Lane bidirectional protected by parked vehicles
Presence of independent cycle lane	Mixed use (cycling, walking and car traffic)	Yes	Yes	Yes
Presence of pedestrian sidewalk	Yes	Yes	Yes	Yes
Presence of car traffic	Yes	Yes	Yes	Yes
Presence of barrier between pedestrians, bikes, and cars	Yes, poles between mixed use and only pedestrian	No poles between pedestrians and bikes. Yes, poles between bikes and cars	No poles between pedestrians and bikes. Yes, poles between bikes and cars	No poles between pedestrians and bikes. Yes, poles between bikes and cars
Levels between sidewalk, bike lane and car lane	All same level	Bike lane lower than sidewalk. Bike and car lane same level.	Bike lane and sidewalk same level. Car lane lower level	Bike lane and sidewalk same level. Car lane lower level.
Sidewalk pavement finish	Sidewalk – small cobblestone, mix use – large cobblestone	Sidewalk – small cobblestone and concrete slabs	Cycling Path – green bituminous material Sidewalk - small cobblestone	50 % sidewalk concrete slabs 50 % sidewalk small cobblestone intersection on asphalt pavement Tactile pavement
Presence of urban furniture	Bollards Trash cans Benches Light Post Water fountain Signages	Bollards Trash cans Benches Urban Furniture for advertisement Fire hydrant	Bollards Light post Urban Furniture for advertisement Technical boxes Bus stop guardrail	Bollards Trash cans Benches Light post Bike Rack Signages Technical boxes
Presence of trees	Yes, few (aprox. 5) Tilia aregentea Big size trees deciduous	Yes, many (more than 10) narrow-leaved ash (Fraxinus angustifolia) Liquidambar (*Liquidambar styraciflua*) Big size trees deciduous	Yes, many (more than 10) Plátano (Platanus spp.) Big size trees deciduous	Yes, many (more than 10) Lote tree (*Celtis Australis*) Big size trees deciduous

to 30 min, while each of the immersive experiences lasted from 70 to 120 s (Table 2). The distances travelled in each immersive experience are presented in Table 2.

2.4. Participants

A convenience sampling approach was used to recruit participants from community centres, senior universities and public libraries. Eligibility criteria for participation included: a) being 60 years or older; b) not suffering from claustrophobia; c) being a Portuguese speaker.

Eighteen individuals, including eleven women and seven men, aged 64 to 90 (average age 74.9: standard deviation =8.40, participated in the study. All participants were Portuguese residents of the Lisbon metropolitan area. The number of participants was devised according to saturation for thematic analysis samples as suggested by (Ahmed, 2025; Guest et al., 2006)).

Thirteen participants lived in Lisbon, and five lived in the metropolitan area. Three were employed, and fifteen were retired. Educational levels varied: ten had lower education (4th–6th year), three completed high school, and five had higher education degrees or postgraduate qualifications. Most (77.78 %; $n = 14$) used Oculus Quest 2 for the first time.

Fig. 6. Screenshots of the videos shown to participants during the experiences.

Table 2
Distances travelled, and duration of the immersive experiment and number of videos used to compose the final video.

Streetscape	Distance travelled (meters)	Duration (seconds)	Number of individual videos included in the final composed video
1) Entrecampos	60	70	7
2) Praça de Londres	110	110	11
3) Avenida do Brasil	120	120	12
4) Duque de Ávila	90	90	9

From the start of the experiment, participants were informed of their right to withdraw at any time, including in the event of experiencing any form of discomfort. There were no reports of motion sickness during the experiment (Ibáñez & Peinado, 2016) and therefore no participants withdraw.

2.5. Experimental protocol

The experimental protocol used consisted of three phases.

Firstly, a **prospecting phase** was conducted. Here, voluntary participants underwent interviews to verify their eligibility based on predefined criteria for study participation, namely: a) being 60 years of age or older; b) not suffering from claustrophobia; c) being a Portuguese speaker.

The second phase involved the **immersive experience**. It began with a brief explanation of the study and the signing of the informed consent form. Participants then completed a short questionnaire that collected basic demographic information, such as age and occupation, as well as their prior experience with VR devices. Following the questionnaire, participants were instructed to explore the four virtual streets using an immersive setup. All participants completed the experience in a seated position, in line with the protocols of Mouratidis & Hassan (Mouratidis & Hassan, 2020) and Kim & Lee (Kim & Lee, 2022). They were instructed to freely explore each streetscape by moving forward from the starting point, with the ability to look around in all directions. Participants were informed that they could remove the headset at any time for any reason and that the researcher would be available to assist with any questions throughout the experience.

We followed the thinking-aloud protocol proposed by Ericsson and Simon (1993) to elicit emotions. While the participants looked at the scenarios, the investigator prompted them to verbalise their thoughts. After exploring each of the four environments, participants removed the HMD. Between each immersive experience, participants responded briefly to their perceptions regarding the quality of public space design, their perception of public space, walkability, fear of falling, ageism, activation, and the well-being of the experienced condition.

The third phase consisted of interviews and questionnaires. After the four navigations, participants were interviewed about their perceptions of the built environment and the use of HMD. Finally, participants completed three questionnaires: Sense of Presence Questionnaire (Slater et al., 1994), NASA Task Load Index (Human Performance Research Group, 1986), and pleasure, activation, and dominance scale (Mehrabian & Russell, 1974).

Before the experiment, a pre-test was conducted with participants with similar characteristics ($n = 4$); 50 % men and 50 % women, with an average age of 68 years. This pre-test allowed us to verify participants' interests and perceptions using the HMD.

The experimental protocol was submitted and approved by the (omitted for blind review) Ethics Committee.

2.6. Data collection and data analysis methods

The subjective data collected from participants was recorded during the experiments.

The thematic analysis method was chosen to analyse the qualitative data (Naeem et al., 2023) derived from transcribing the thinking-aloud process and interviews. It is a method for identifying, analysing, organising, describing, and reporting themes within a dataset (Braun & Clarke, 2006). It provides advantages such as flexibility of approach and is recommended for interdisciplinary studies. Due to the extensive qualitative data in this study, MAXQDA software was utilised to organise and arrange the generated codes into themes and subthemes, as detailed later. Initially, the data was explored inductively, without preconceived categories, allowing for the emergence of unexpected themes based on the participants' experiences. Themes were identified by coding words,

sentences, or phrases that emerged directly from the data. Later, we applied a deductive approach, which involved the application of the theoretical framework (Câmara Municipal de Lisboa, 2018; Gehl, 2010; WHO, 2007), that identified pre-existing and expected concepts that emerged from interviews. In Supplementary Material, representative quotes from anonymised participants are included. Ultimately, the analytical narrative is contextualised and deliberated in connection with established literature in the discussion section.

3. Results

In the present study, four themes and 25 subthemes were identified. The four themes encompassed the following topics: i) public space quality for older people; ii) how older people share the outdoor public space with another road user groups; iii) how older people feel within the city; and iv) how older people perceive the public space with digital technologies.

The subthemes were initially inducted in sub-themes based on interviews and hence deduced from (Gehl, 2010; Mehta, 2021; WHO, 2007) forming an inductive-deductive approach.

Fig. 7 illustrates the themes and subthemes as indicated by (Braun & Clarke, 2006) and display the number of citations for each sub-theme. Additionally, Fig. 8 to Fig. 11 display those citations per streetscape. Due to the study's objectives, subthemes related to digital technologies were mentioned less frequently. Although we identify and categorize them into a specific theme, we did not analyse them per streetscape.

3.1. Theme 1: Public spaces quality for older people

In this study, we assume that older adults recognise and evaluate public spaces by considering their physical and tangible characteristics. This theme refers to the space that is open to the general public, which generates public use and active or passive social behaviour, and where people are subject to the general regulations that govern the use of the city space (Mehta, 2021).

For the senior public, **dimensions and geometry** are fundamental and associated with the materiality of pavements. Materiality here stands not only for the structural integrity of the material but also to its aesthetic, tactile and environmental characteristics. Praça de Londres for 15 times was mentioned as a large and positive space, ahead of all other spaces.

The presence of cobblestone (see Fig. 6) and the perception regarding pavement **materiality** were similarly mentioned, with between eight and 10 mentions in every space, mainly considering the risks of the irregularities.

Regarding **legibility** properties, a crucial role in orienting the senior public in urban spaces, distributed in factors such as colours, textures, contrasts and signage, within the array of visual information. Entrecampos had five negative comments related to these aspects, the highest number among the four streetscapes tested.

The design and implementation of measures for the resolution of architectural barriers and implementation of **urban furniture** aim to provide comfort and safety for pedestrians and cyclists. Elements such as bollards, guardrails, and variations in curb height, identified on the cycling paths, have led to a spatial dynamic that separates each mode of transportation (cars, bicycles, and pedestrians). Praça de Londres received more positive mentions ($n = 8$).

Facades, permeabilities and commercial spaces significantly contribute to the perception of the city by its users who walk within it. Participants highlighted these characteristics as factors encouraging them to walk, mainly in Praça de Londres and Duque de Ávila.

The **height of surrounding buildings** and enclosure are attributes that influence the perception of the city. Diversity of streetscapes, surroundings of urban areas, and the unique architecture of each building are presented as attributes that influence users, highlighting the relationship of these elements with the visual perception of users walking.

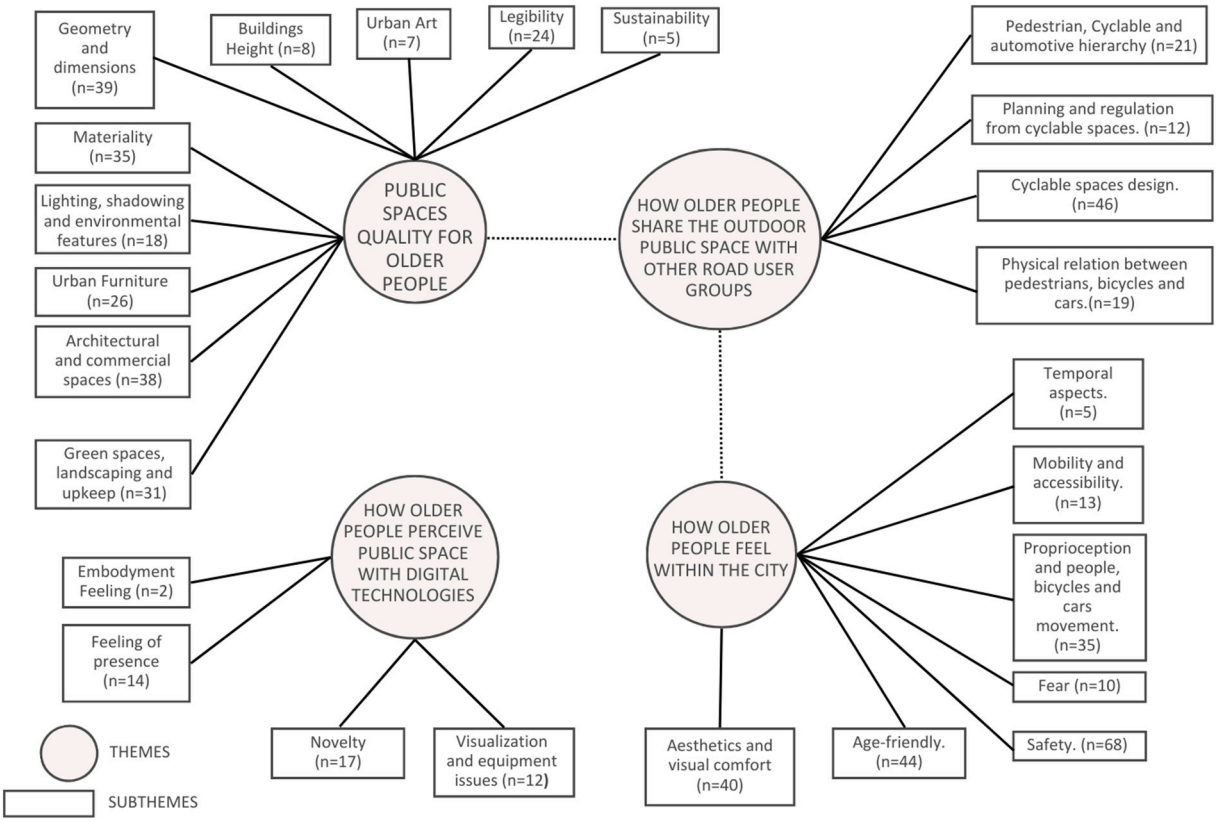

Fig. 7. Thematic map indicating themes and subthemes.

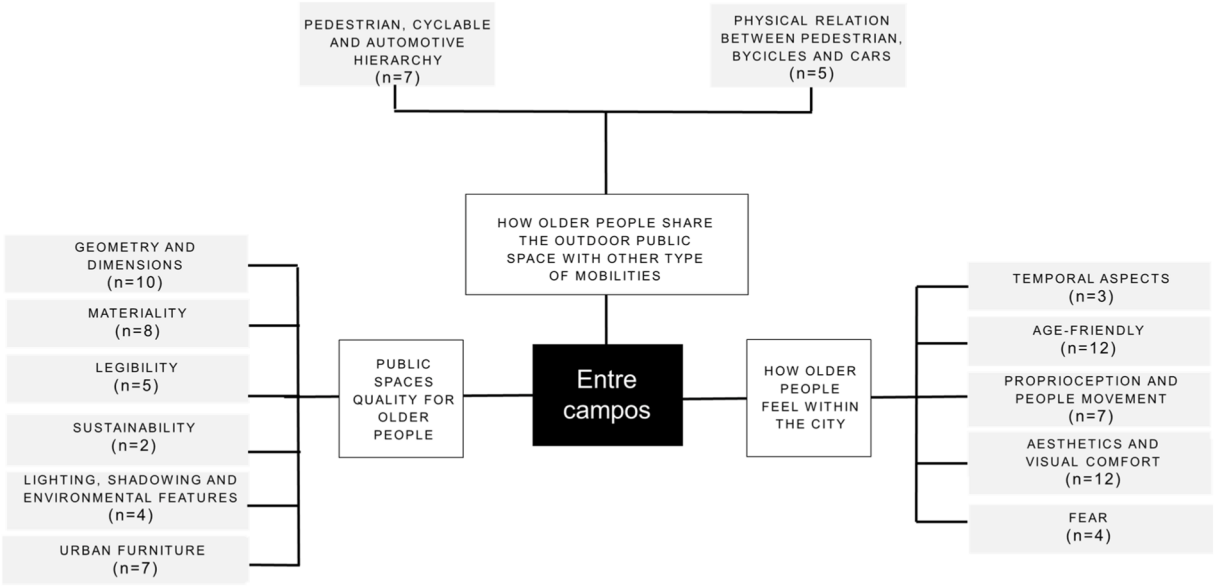

Fig. 8. More frequently mentioned themes and subthemes for Entrecampos.

These attributes were mentioned in three streetscapes, with Praça de Londres and Entrecampos receiving no mention of the buildings around it, possibly because it is the most spacious and open area and, therefore, buildings are less impacting.

Four comments mentioned **urban art**, reflected on Avenida do Brasil, in a large graffiti on a building, which is unusual in the city of Lisbon. Although public art is composed of sculptures, murals, graffiti, decorative objects, and others, the studied routes supposedly contained few artistic references.

The presence of **lighting, shadowing and environmental features** for protection against weather conditions were highlighted. Environmental conditions, such as wind and noise, were negatively reported by participants in Entrecampos, Avenida do Brasil, and Av. Duque de Ávila.

The subtheme of **green spaces, landscaping, and upkeep** identified urban green spaces as potential places for contemplation and social cohesion. Participants indicated that the presence of trees influences their well-being while walking through the streets of Lisbon. Avenida do Brasil was negatively mentioned five times in relation to improper maintenance of roots, cleaning, and removal of leaves.

The concern for **sustainability** was reflected in five comments in a sum for all places. Participants understand active mobility as a strategy to reduce the number of cars on the streets, hence inviting people to walk and improve the air quality of the city.

3.2. *Theme 2: How older people share the outdoor public space with other road user groups*

This theme consolidates concepts regarding the relationship between older adults and the sharing of pedestrian public space with different user groups, such as cycling and scooters. Conceptually, it incorporates active mobility, described as the use of walking and cycling in single trips or within a trip in combination with public transport (Gerike et al., 2016), extending to active travel, as defined by Cerin et al. (2017) as walking or cycling to a destination. It is not only the criteria of each mode of mobility that will determine the design of public space, such as dimensions, layouts, and signage, but also the relationships between the different mobilities and the requirements of each (Herce, 2009).

The subtheme **pedestrian, cyclable, and automotive hierarchy** encompasses perceptions related to the hierarchies of active modes of transportation, which include other vehicles besides bicycles, such as cars. In Av. Duque de Ávila and Entrecampos, with more intense bicycle and automobile traffic, participants reported that pedestrians can face negative hierarchy subversions, reported in eight and seven mentions, respectively.

The subtheme **planning and regulation of cyclable spaces,** dependent on well-structured public policies, was highlighted by participants who stated the need for proper planning to implement changes in the city's sidewalks and streets and legislation that protects pedestrians and cyclists, where Avenida do Brasil represented the main area of concern, with five mentions.

Considering the **design of cyclable spaces**, there were 46 comments. Avenida Duque De Ávila and Praça de Londres were rated better than Avenida do Brasil, where the bike lane is at the same level within the sidewalk. Concerns included lane proximity and bidirectional lanes, while visibility predictability, colours, and signage were positively mentioned.

In the subtheme of **physical relation between pedestrians, bicycles, and cars, participants'** responses agreed that allocating sufficient space between these public space actors is mandatory to regulate the relationship between the forms of mobility, with Avenida Duque de Ávila and Entrecampos representing a closer and unfriendly relation, with five negative mentions each.

3.3. *Theme 3: How older people feel within the city*

Among the perceptions of older adults experiencing public spaces, perceptions related to space include social capital (Mazumdar et al., 2018; Wood et al., 2008), safety (De Donder et al., 2013; Wu et al., 2020), belonging (Biggs & Carr, 2015), agency (Hauderowicz et al., 2020) among others that are part of daily life. The city is a complex organism, and older adults, as actors in urban space, face a series of conflicting behaviours toward them. On the one hand, many feel respected, recognised, and included. On the other hand, they feel there is a lack of respect from the community, services, and public policies. Addressing whether the spatial dimension has an ageist design (WHO, 2021), participants clearly advocated for an urban design that promotes the inclusion of older adults in public space.

The perception of **temporal aspects** is a fundamental aspect of daily life that undergoes changes throughout one's life. In the social sciences, temporality is explored in relation to how humans perceive time and how time is structured within social contexts (Ialenti, 2020)). The ubiquity of temporality in real life can be exemplified by traffic light

phases and how different people perceive the same linear time. The crossing time at a pedestrian crosswalk can be miscalculated in environments with a lot of visual information. Participants mentioned aspects related to time perception five times in their comments.

The participants addressed the need for measures to increase their **mobility** and the **accessibility** of public spaces. Musselwhite and Haddad (2010) define mobility as the amount of travel undertaken and accessibility as the number of opportunities reached. Building on this formulation and adapting it to our case, we define accessibility in terms of both tangible aspects, such as sidewalks, and intangible elements, such as auditory alerts (representing opportunities). Mobility, on the other hand, is associated with the physical act of walking and using transportation (representing the travel undertaken). Such aspects were mentioned 13 times.

Asked about the presented spaces and whether they had **age-friendly** characteristics, participants' perceptions formed a subtheme. Praça de Londres received 10 positive mentions, while Entrecampos, although receiving five positive mentions, received six criticisms regarding its age-friendliness.

The subtheme of **safety** addresses both non-traffic accidents (i.e. a pedestrian falling in a public space) and traffic crashes (a pedestrian hit by a vehicle) (International Transport Forum, 2012), and received attention from participants 68 times, reflecting the importance of this aspect. Praça de Londres received the most positive comments on safety perception ($n = 14$). On the other hand, although Avenida do Brasil received six positive comments, it had 13 negative comments regarding perceived safety.

Proprioception, the sense that allows us to perceive the location, movement, and action of body parts, and connects with other senses to locate external objects relative to the body, was directly related to the number of people and the surrounding space, reported by participants on 35 occasions. Praça de Londres provided an experience with more space and less movement of people, bicycles, and cars, reflected in seven positive comments. In contrast, spaces like Av. Duque de Ávila, where there were more people, bicycles, and cars, received 15 negative mentions.

An attribute that participants spontaneously mentioned as an age-friendly characteristic is the **aesthetics** of the city's natural environment. Participants in this study provided their impressions of urban spaces, highlighting Praça de Londres and Avenida do Brasil with 10 positive mentions each. On the other hand, Entrecampos received five negative mentions, while Praça de Londres received only one negative mention, and Avenida do Brasil and Avenida Duque de Ávila were not mentioned negatively.

The last subtheme is **fear**, a basic emotion (Ekman, 1992), considered as an expectation of failure to achieve a goal (Stein & Trabasso, 1992). In our study, Entrecampos was the space with the highest number of mentions ($n = 4$) of this subtheme.

3.4. Theme 4: How older people perceive public space with digital technologies

Digital tools offer new methodological perspectives for contemporary architectural practice. The pace of this progress is driven by the continuous introduction of new devices, sensors, computer programs, and other technological resources. In our study, we used immersive VR technology, defined by Han and Lee (2023) as the creation of a realistic, three-dimensional spatial environment, making it possible to investigate and analyse how people visually perceive a real urban environment.

The use of immersive virtual reality (VR) for architecture is a growing phenomenon, encompassing design (Silvennoinen et al., 2022), real estate (Xiong et al., 2022), and fear of falling (Leite et al., 2019).

The **feeling of presence** is defined as the sensation of "being there" in the virtual environment. Comments indicated in Supplementary material show that the experience achieved a positive result regarding the feeling of presence with older adults in 14 mentions.

VR users can feel that they have been transported to a new location (place illusion), that the events happening are real (plausibility illusion), and that they can feel embodied by an avatar, enhancing the experience. In this study, an avatar was not included when the participants observed the space; hence, there was no embodiment feature. However, two mentions about the lack of an avatar or body parts considered this perception and pointed to a subtheme.

Novelty is defined as the process of experiencing or encountering something different from the objects regularly encountered. Regarding this aspect, we considered the participants' perceptions of virtual reality devices. With 17 mentions, the use of VR and HMD was a positive novelty for the participants.

During the experiences, there were some occurrences related to the operation of the equipment, reflecting a subtheme related to **visualisation and equipment issues**. In this subtheme, we included comments from participants during the sessions, where they described occasional distortions in images and issues with the operation of the equipment.

3.5. Correspondence between themes, subthemes and streetscapes

In Fig. 8, Fig. 9, Fig. 10, and Fig. 11 identifying the subthemes more frequently mentioned concerning each specific streetscape is possible. The diagrams indicate, but do not specify whether these are referred to positively or negatively. In the Supplementary Material, there are mentions for each subtheme where we identified positive and negative aspects. The discussion section explains each streetscape. We also added the total number of comments per participant.

It is noteworthy that four subthemes – namely, feeling of presence, embodiment, novelty, visualisation and equipment issues - were omitted from the table due to their indirect relevance to each of the four spaces but rather pertain to the overall immersive experience. (See Fig. 12.)

4. Discussion

In this study, we advanced in exploring the interaction between urban public spaces and older adults, highlighting how space shapes perceptions and influences decisions. While navigating the urban environment, older adults are guided by their spatial perceptions within the temporal experience.

The tracks and distances used in our simulations are appropriate according to the literature, usually short (Distefano et al., 2021) and within time intervals found in the 15-min city concept (Di Marino et al., 2023; Ulloa-Leon et al., 2023).

In this study, we sought to understand the experience of public space in the city of Lisbon for the older population so that the study's conclusions can be used by designers and decision-makers.

To answer the initial question about older people's perceptions of the quality of public spaces for walking, this study revealed a set of factors associated with the physical space that should provide safety and comfort for older adults. We highlight the pleasure associated with the presence of nature and urban art, the understanding of changing paradigms of mobility and sustainability, contrasted with the fear of uneven pavements and the cognitive and physical decline that hinders movement in environments with heavy traffic, as well as typologies with less permeability.

One relevant aspect of our participants' perception was the fact that, although they report some conflicts with bikes and scooter, older adults understand and accept active mobility as a strategy to reduce the number of cars on the streets, hence inviting people to walk and improve the air quality of the city. This adds to the review by Lee and Sener (2023) on the perception of e-bikes and their conclusion that policies and education are needed to promote the acceptance of e-bikes.

Addressing the main aspects of public spaces qualities, geometry and dimensions of space are not factors that, per se, provide the desired quality for older adults. Nevertheless, when including cycling spaces, a

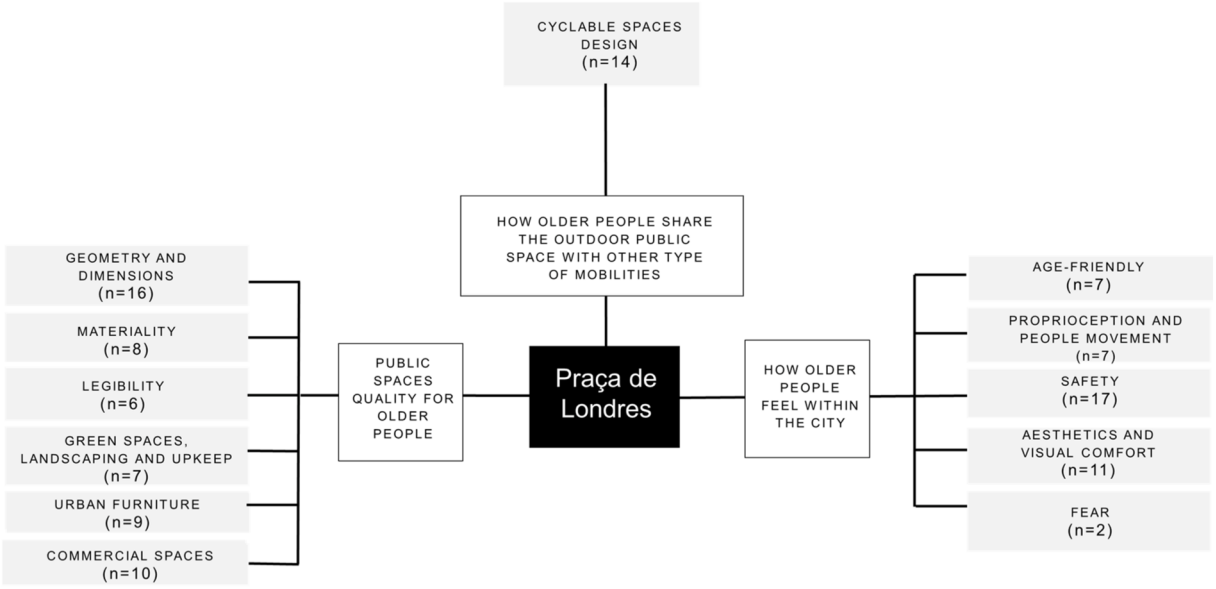

Fig. 9. More frequently mentioned themes and subthemes for Praça de Londres.

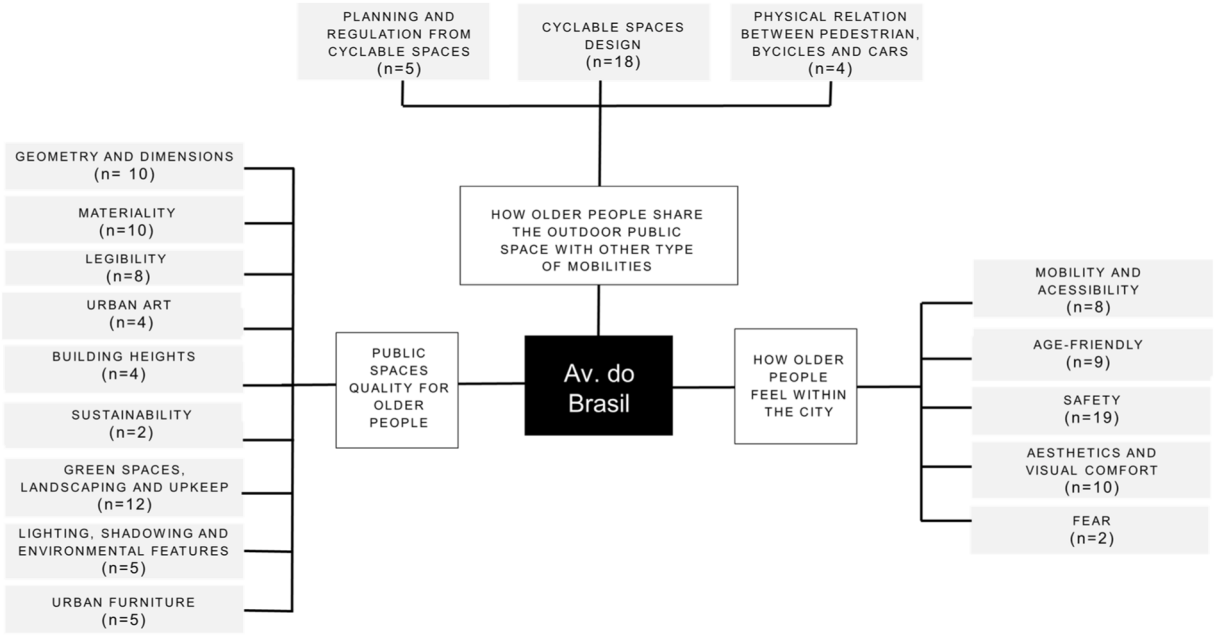

Fig. 10. More frequently mentioned themes and subthemes for Avenida do Brasil.

minimum buffer is essential to provide safety, as identified in previous studies, mainly from a cycling perspective (Rodriguez-Valencia et al., 2022; Walks, 2010) and public policies recommendations (NACTO, 2011; WHO, 2017), reinforcing the lack and request for more studies addressing the streetscape typology.

We identified that the materiality of the sidewalk pavements, although a cultural heritage of the city of Lisbon (da Silva & Pereira, 2022), show many difficulties due to the irregularities of limestone stones (Alves et al., 2021). Without proper maintenance, this pavement imposes discomfort, provokes insecurity, and increases fear and the risk of falls, also mentioned in other studies (Kohijoki & Koistinen, 2019; Walford et al., 2017). These aspects were evident in Entrecampos, Avenida do Brasil, and Avenida Duque de Ávila.

Also, considering the pavement, its colours, shades, and characteristics associated with the legibility of space, such as traffic signs, cycle path colours, and road markings, were reported by study participants as elements that can enhance the feeling of safety. However, especially on Avenida do Brasil (Fig. 13), where the cycling circulation space is at the same level and within the pedestrian area, there is a perception of insecurity. Despite the presence of different materials, pavement colour, road markings, and traffic signs in a prominent manner, these are still insufficient to bring safety to the walkability of this streetscape.

Benches, resting places, water fountains, parking meters, service boxes, and lids were mentioned as part of the urban furniture that should be integrated into the urban landscape but with a careful design so that they do not create architectural barriers for the older adults. Trees, benches, and bushes work as natural barriers between the sidewalk and the cycling lanes, and participants also referred to them as elements that provide increased safety and physical and visual comfort.

Regarding the sharing with cycling spaces and how older adults

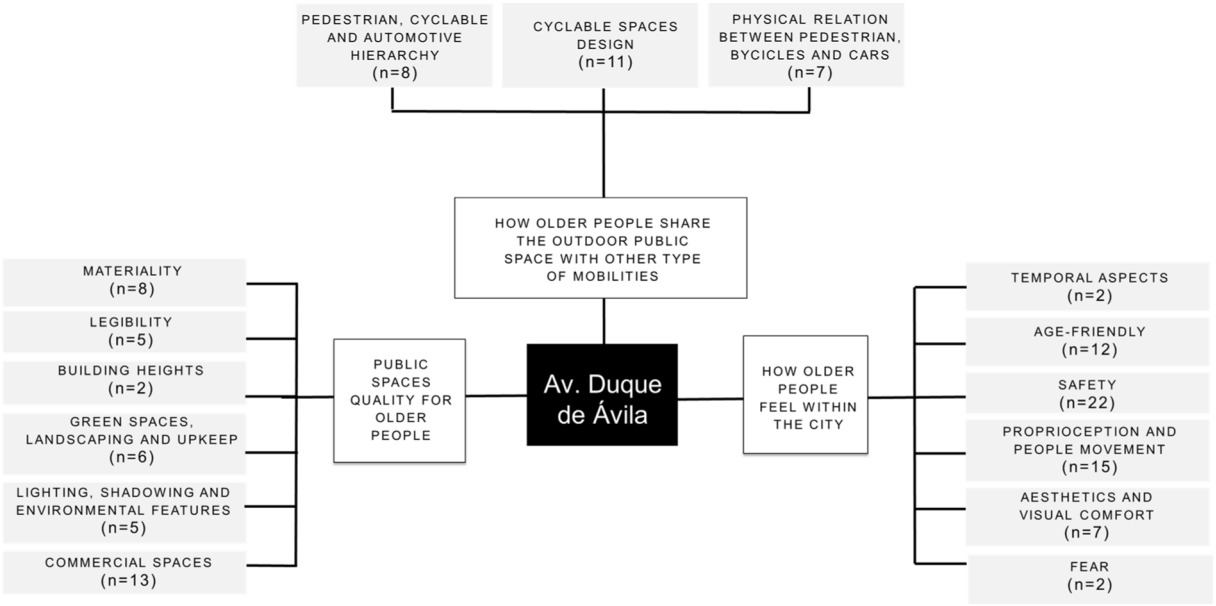

Fig. 11. More frequently mentioned themes and subthemes for Av. Duque de Ávila.

Participant	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Comments	40	30	38	35	49	34	37	46	30	35	22	30	28	24	28	54	37	48

Fig. 12. Number of comments per participant.

Fig. 13. Cycling indication as a sign and floor painted (Avenida do Brasil).

relate to the cycling lanes, Avenida do Brasil and Avenida Duque de Ávila, with their bidirectional cycling lanes, caused greater insecurity among older adults. This corroborates Che et al. (2021), where the author suggests that the perception of fear associated with the presence of bicycles moving in the same direction as the pedestrian (overtaking encounter) is greater. Conversely, when the bicycle or scooter is approaching from the opposite direction, it is possible to see it coming and act. Whenever possible, unidirectional lanes are recommended and architectural barriers are highly indicated, also referred to in studies as promoters of safety for pedestrians and cyclists (Schimek, 2018; van Petegem et al., 2021).

Cycling lane typologies are preferred, cases of Praça de Londres and Avenida Duque de Ávila (Fig. 6), designed with physical segregation between pedestrian and cycle lanes and a difference in pavement level provided by a higher curb separating the two spaces. These cases demonstrate an effective use of architectural barriers as an attribute to be employed for spatial segregation, providing comfort and safety.

Mixed-use and shared streets are a typology that notably causes discomfort for older adults and should be avoided according to other authors (Wang et al., 2022). In this study, the typology of Entrecampos, although having traffic calming signals, also causes confusion and discomfort for older adults, especially because the entire pavement being of the same colour and affects a clear legibility of the space.

At the medium scale – in site planning – people and activities are dispersed when buildings are placed at great distances from one another, with entrance areas and residences oriented away from each other, as Jan Gehl states in “Life between Buildings” (Gehl, 2011). Avenida do Brasil reflected this, with the presence of a wall and fences along most of

the streetscape, few permeability, fewer people and commercial areas, causing participants to feel fear, uncomfortable and a lower potential for social cohesion compared to the other three streetscapes. Conversely, the presence of commercial areas is a clear invitation to use public space (Gehl, 2010). Avenida Duque de Ávila and Praça de Londres, where there is a higher concentration of commercial activities and a variety of details to appreciate, such as facades, terraces, shop windows, doors, and windows are good examples.

The presence of other individuals in public spaces is indicative of a welcoming environment favourable to social interaction (Gehl, 2010). Multigenerational spaces promote such interactions (WHO, 2007) and facilitate engagement between residents and pedestrians. Avenida Duque de Ávila and Praça de Londres, with lower buildings and commercial areas exemplify these characteristics, in contrast to Entrecampos and Avenida do Brasil, where buildings exceed four storeys.

Green spaces (Borst et al., 2008), time of year, and season (Wang & Zhao, 2020) are determinants and affect people's perceptions due to factors such as temperature and sun exposure. Conducted during spring, it revealed positive aspects regarding the shading produced by trees and the presence of greenery. However, the irregularities caused by roots on the pavements and the falling leaves during autumn were identified as risk factors for walkability.

It is notable that the study participants reported a greater perception of safety and a lower risk of accidents when the bike lanes and paths included a physical separation from pedestrian mobility. This effect was observed in Praça de Londres, along with attributes of the public space such as the presence of urban furniture and lower buildings. The significant number of mentions ($n = 68$) from participants about the safety of the streetscapes underscores its importance.

Studies that identify the main causes from fear in public spaces for older adults as fear of falling (Lee et al., 2018), crime (Patel, 2020), and insecurity (An & Yoshida, 2018) considers similar responses from the participants from our study, as low percentages of sidewalks and their bad quality, high-rise buildings and high traffic speed. Urban design can significantly contribute to minimising fear and improving the well-being and mental health of urban space users. We emphasise that the presence of other people (social capital), the quality of the pavements, and legibility are mandatory for a positive experience in public environments. Praça de Londres and Av. Duque de Ávila reflected this as the best experiences among the studied spaces.

Therefore, the proper incorporation of active mobility in public spaces requires an age-friendly architecture in the urban regeneration of public spaces (Buffel et al., 2012). The presence of active mobility, requires an approach that considers physical, cognitive, and organizational ergonomics (IEA, 2015) in addressing the spatial complexity, physicality, and organisation of each space. Demanding safety, public space older users demand less proximity between pedestrians and other modes of circulation (cyclable and automotive). von Stülpnagel and Rintelen (2024), argue that sharing a street without clear separation or prioritisation seems unsafe not only for cyclists but also for car drivers.

Public focus on aspects such as sustainability (Gehl, 2010), public health (Adriazola-Steil et al., 2021) and the promotion of physical activity (Gerike et al., 2016) drive an urgent update in urban space management for the integration of active mobility. Policies aimed at organising and standardising interventions for its inclusion and strategies to tackle an ageist urban design.

The Public Space Manual (Câmara Municipal de Lisboa, 2018) advocates for the compatibility of pedestrian circulation with vehicular traffic (bicycles and automobiles) and recognises pedestrians and cyclists as vulnerable road users. Following other authors, such as Gehl (Gehl, 2010), we stress that it is necessary to include older adults as actors if we aim to achieve a dynamic city described as safe, sustainable, and healthy. Also, considering the sustainability claimed by the insertion of active mobility lanes, this study provided compelling evidence that older adults should be involved in streetscape's retrofits.

The Global Guide, Age-Friendly Cities (WHO, 2007), argues that an age-friendly city adapts its structures and services to be accessible and inclusive for older people with diverse needs and capacities. To update the structure of outdoor public spaces and achieve mobility in the city of the future, we suggest more exploratory studies like this to understand older citizens' perceptions of urban architecture.

In the four streetscapes, through immersive visualisation with 360° videos, participants were able to evaluate the streets as if they were "present", highlighting the importance of active mobility as a sustainable and health resource (i.e., active ageing) for the city. As a resource to understand how older people relate with technology, the use of immersive images was a highly accepted proposal.

4.1. *Innovative approaches presented by this study*

The methodology explored in this study helped enhance our understanding of older adults' perceptions of street quality. It also provided empirical data that can support decision-making in public policies aimed at promoting age-friendly cities and active mobility.

Although qualitative analysis does not aim to generalise collected data, we decided to analyse the four streets collectively rather than individually, although a separate analysis could also have been pursued.

By applying thematic analysis to these four distinct street cases, we identified a set of themes and sub-themes that are applicable across all street types analysed in Lisbon. While this approach does not allow for quantitative generalisation, it enabled us to develop a set of dimensions that had not previously been defined for Lisbon's streets. Because these dimensions were not established beforehand, it was not possible to begin the study using a quantitative approach, such as questionnaires.

For future research, it will be important to examine whether these dimensions can be more broadly generalised to other streets in Lisbon, other Portuguese cities, or even different countries.

As mentioned in the introduction, the increase of longevity is a trend not only in Europe, but worldwide. Reframe the cities to attend their requests is mandatory issue and we have addressed exclusively for this public in this study. The studies we have compared (Han & Lee, 2023; Kim & Lee, 2022; Lager et al., 2021; Llinares et al., 2020; Mouratidis & Hassan, 2020; Walford et al., 2011) have none or very few older adults participants, except for (Lager et al., 2021; Walford et al., 2011). Our study advances therefore by proposing new methods for older people participation.

Studies utilising Google Street View or similar images (Han & Lee, 2023; Kim & Lee, 2022; Mouratidis & Hassan, 2020), primarily relied on images captured from the middle of the street, reflecting the perspective of vehicles. A key advancement of our study is the use of a sidewalk perspective, replicating the viewpoint of a regular pedestrian.

Han and Lee (2023) showed that 360 ^{o} videos are more realistic and suggests better outcomes from participants responses. Additionally, and instead of using static positions such as in (Llinares et al., 2020), our study explores a walking simulation where the videos change every 10 s, presenting different viewpoints of the streetscape.

Results and conclusions from studies have primarily focused on evaluating users' experiences in areas such as comfort (Han & Lee, 2023; Kim & Lee, 2022), safety (Han & Lee, 2023; Kim & Lee, 2022; Llinares et al., 2020; Mouratidis & Hassan, 2020; Walford et al., 2011), cleanliness (Han & Lee, 2023), presence (Llinares et al., 2020), aesthetics (Kim & Lee, 2022; Walford et al., 2011) and mobility (Lager et al., 2021). By applying a mixed-method approach combining deductive and inductive analysis, our study uncovered significant insights, highlighting perspectives that have been underexplored or overlooked in previous research, including sustainability, age-friendliness, fear, and proprioception.

One of the most important considerations highlighted in this study is that older adults assumes that the reframe of public space should include accessible and ergonomic urban furniture, clear separations from the bike lanes and more commercial stores, suggesting an increase in the liveability of the city. Other important aspects, confirming existing

literature, include: public space design (Mouratidis & Hassan, 2020); architectural perception (Mouratidis & Hassan, 2020); vegetation (Llinares et al., 2020); number of lanes (Llinares et al., 2020); human scale (Kim & Lee, 2022); enclosure (Kim & Lee, 2022); legibility (Kim & Lee, 2022); crowdedness (Kim & Lee, 2022); materiality (Walford et al., 2011); and traffic (Walford et al., 2011).

We emphasise the importance of thematic analysis as a valuable tool for future studies, contributing to a deeper understanding of active mobility and the renovation of public spaces.

4.2. Preliminary recommendations for making streets more adaptable to older people

Although this paper does not aim to provide specific recommendations for designing streets that are more adaptable for older individuals, the authors deemed it useful to summarise key aspects that, according to the perceptions of older people, should be addressed in public space design and aiming to assist in decision-making within the scope of public policies.

The first key point is the importance of involving older people in the design of public spaces, a view supported by several scholars.

Regarding the physical aspects of streets, we emphasise the need to accommodate the following elements:

- Pavement materiality: Ensuring that pedestrian pathways are free of irregularities (in terms of material and maintenance) to enhance safety and reduce the risk of falls.
- Visual and textural considerations: Attention to colour, texture, and signage is necessary to improve contrast and legibility, making the environment more navigable.
- Separation of pedestrian and cycling lanes: Using physical barriers to distinguish between pedestrian and cycle lanes, enhancing safety and reducing the risk of collisions. The integration of cycle and pedestrian lanes at the same level was identified as problematic because it increases proximity and could lead to confusion. Addressing this can help resolve the issues of negative hierarchy that older people experience.
- Lighting and shade: Proper street lighting is essential for safety, and the inclusion of shaded areas can protect against adverse weather conditions.
- Green spaces: The incorporation of trees and green spaces contributes to a sense of well-being and improves the aesthetic quality of the urban environment.
- Vibrant neighbourhoods: A lively neighbourhood with ongoing activities such as commercial spaces and attractive architecture encourages older individuals to engage in walking and outdoor activities.

The subjective perception of time, as discussed previously in this paper, is also a significant factor. Given the increasing visual complexity of streets, it is recommended to create better conditions for walking, such as allowing longer crossing times at traffic signals and ensuring greater separation between faster-moving vehicles (bikes and cars) and slower pedestrians.

An essential observation is that older people recognise the importance of ecological sustainability in urban development. This suggests that they are open to embracing changes in the city, provided that proper planning ensures the protection and safety of pedestrians.

4.3. Strengths and limitations of the study

A limitation of this study is the fact that it was conducted only in Lisbon. Indeed, the architectural, topographical, and landscape characteristics of Lisbon, with its unique and local features, mean that the results might differ if the study were conducted in other cities with different conditions, such as climate, morphology, and population density. Nevertheless, besides the results for Lisbon, the strength of this work lies in defining a methodology that can be applied in other contexts to produce comparable studies.

Another limitation of this study is related to the equipment used. Although immersive devices produce a sense of presence with audiovisual characteristics, the ones we used did not encompass tactile perceptions, olfactory sensations, or climatic conditions like temperature, wind and rain. The study reinforced the proprioceptive and realistic perception of the body. Nevertheless, physical actions such as walking and moving were not included which limits the experience of space.

Given the exploratory nature of the study, we selected thematic analysis as the research method to analyse the results. The sample consisted of 18 participants, according to literature recommendations (Ahmed, 2025; Guest et al., 2006), chosen through snowball sampling. This approach proved advantageous as it allowed for an in-depth exploration of the extracted data.

It is worth noting that the use of VR places all participants in equal situations, a positive argument. The inclusion and digital literacy offered by using the equipment was a valuable addition for the research participants and in some cases, sparked interest in using it again.

The portability of the Oculus Quest 2 equipment was crucial for conducting interviews with the study participants. Although some older adults initially resisted using the equipment, participants who had ever used it before ($n = 14$; 77, 7 %) mentioned that it was a pleasant and interesting experience.

5. Conclusions

Due to the rigour of our research methodology, we were able to offer an exhaustive and intricate portrayal of the seniors' perceptions and viewpoints regarding the public space in four locations in Lisbon. As a result, we provide our analysis of how 360° video narratives contribute to understanding older people's spatial perceptions and ergonomic requirements.

By correlating the tangible (physical) and intangible (perceptions) aspects of pedestrian spaces with the presence of active mobility, we identified perceptions such as pleasure, fear, and safety and materiality of the pavements, presence of urban furniture, green areas, and legibility of the space as elements that significantly influence the decision-making of older adults when walking.

It is noteworthy that the presence of active mobility exerts a positive influence, demonstrating that large, unobstructed, and physically segregated spaces for walking encourage older adults to engage in walking. Active mobility is well-regarded as a vector for active ageing and for promoting the reduction of motor vehicles enhancing well-being by reducing noise and pollutant emissions.

However, segregation of spaces is considered imperative in high-traffic areas with significant pedestrian, bicycle, and vehicular movement. This necessitates the implementation of barriers and clear informational signage to facilitate effective spatial orientation In coexistence zones, pedestrian priority must be ensured, and vehicular boundaries clearly defined. Given the challenges these environments pose for older adults, continuous monitoring and data collection are essential to identify potential conflicts and enhance overall well-being.

Immersive visualisations through 360° spherical videos have proven valuable, powerful, and promising tool for evaluating built spaces. The emergence of improvements in equipment, such as cameras and HMDs, software, and HMD devices, will certainly enhance the agency and quality of the immersion offered.

In the light of the increasing attention toward active mobility and the integration of new mobilities solution within the urban fabric (Adriazola-Steil et al., 2021; Brüchert et al., 2017; Filippova & Buchoud, 2020), this study brings new insights and addresses the older individuals' requests to the discussion, contributing for the complex challenge of designing multigenerational public spaces.

This study supports that the adoption of immersive technology offers

significant advantages in evaluating and understanding the interaction between users and public spaces. Despite being experienced virtually, participants managed to transpose themselves into the physical space and expressed elements such as climate, lighting, traffic, and noise, which are determinant elements in the perception of the city during the pedestrian experience.

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CRediT authorship contribution statement

Marcos Figueiredo: Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Sara Eloy:** Writing – review & editing, Supervision. **Sibila Marques:** Writing – review & editing, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

The data that has been used is confidential.

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